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Nesta Edição

Usando os dados dos Relatórios de Avaliação de Danos da Defesa Civil, o presente estudo investiga a relação entre os danos causados por desastres naturais e o desenvolvimento local em nível municipal no estado do Ceará, Brasil. Os resultados mostram que uma melhor infraestrutura urbana e de abastecimento de água, menor densidade populacional, uma maior proporção de receitas próprias em relação à receita total estão associadas a menores danos causados por desastres. No entanto, o desenvolvimento econômico em termos de PIB per capita exibe uma relação em U com o impacto de desastres naturais entre os municípios, refletindo os possíveis retornos decrescentes de investimentos preventivos devido ao alto ambiente de risco de eventos climáticos extremos que é típico dos municípios.

Natural Disasters and Local Development in Northeast Brazil: The Case of Droughts and Floods in Ceará State*

Victor Hugo de Oliveira†, João Mário S. de França‡, Francisco Mário V. Martins§

Abstract

Using data from the Damage Assessment Reports from the Civil Defence, the current study investigates the relationship between the damages caused by natural disasters and local development at the municipal level in Ceará State, Brazil. The results show that better urban and water supply infrastructure, smaller population density, a higher proportion of own revenues regarding total revenues are associated with smaller disaster damages. However, economic development in terms of GDP per capita exhibits a U-shaped relationship with the impact of natural disasters across municipalities, reflecting the potential decreasing returns of preventive investments due to the high hazardous environment that involves municipalities.

Key-words: Natural Disasters, Local Development, Ceará, Brazil.

Resumo

Usando os dados dos Relatórios de Avaliação de Danos da Defesa Civil, o presente estudo investiga a relação entre os danos causados por desastres naturais e o desenvolvimento local em nível municipal no estado do Ceará, Brasil. Os resultados mostram que uma melhor infraestrutura urbana e de abastecimento de água, menor densidade populacional, uma maior proporção de receitas próprias em relação à receita total estão associadas a menores danos causados por desastres. No entanto, o desenvolvimento econômico em termos de PIB per capita exibe uma relação em U com o impacto de desastres naturais entre os municípios, refletindo os possíveis retornos decrescentes de investimentos preventivos devido ao alto ambiente de risco de eventos climáticos extremos que é típico dos municípios cearenses.

Palavras-chave: Desastres naturais, desenvolvimento loca, Ceará, Brasil.

JEL: Q54, R11, R58.

1 INTRODUCTION

The increasing incidence of climate-related and geophysical disasters has caused devastating impacts on social and economic development worldwide, generating direct costs that amount US$ 2,908 billion in the last two decades (1998-2017). While the majority of fatalities were

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due to geophysical events (mostly earthquakes and tsunamis), 77% of all direct costs were caused by climate-related disasters (UNISRD, 2017).

In Brazil, a developing country highly exposed to extreme weather events, there were 38,996 records of natural disasters with a further predominance of droughts (51.3%) and floods (32.7%) between 1991 and 2012. In this period, on average, 6 million people were affected by natural disasters (CEPED, 2013). The total cost of damages amounts R$ 137 billion (US$ 119 billion PPP) between 1995 and 2014 (CEPED, 2016).[5] In addition, the negative prognoses on climate change tend to further accentuate these impacts in Brazil (IPCC, 2012; PBMC, 2015), which demands investigations about how economic development can contribute to mitigating the impacts of environmental shocks on population well-being.

The occurrence of natural disasters is always preceded by the existence of specific physical and social conditions that are generally referred to as disaster risk (Wisner et al., 2004, UNISDR, 2009, 2011). In this sense, the usual formulation of disaster risk is associated with the notions of vulnerability, exposure and the natural process itself, accompanied by possible adverse effects in the future.

The literature has sought to approach this concept of disaster risk as a way to investigate and have a better understanding of the influence of these natural phenomena on the risk of extreme impacts on the population and economy of an affected country or region. For instance, Zhou et al. (2015) analyzed the level of the relative risk of major natural events in China and found that high exposure was a significant risk factor and that high vulnerability magnifies levels of disaster risk. Okuyama and Sahin (2009), in turn, have demonstrated that flood risk is not only rooted in extreme hydrometeorological events, but that there are important social factors, such as population growth, land use change, settlement patterns, and the distribution of poverty that greatly aggravate the risk of flooding.

[5] Real value of 2014 based on the GDP deflator (CEPED, 2016).

Some empirical studies have demonstrated a strong negative relationship between economic development and the risk of death from natural disasters (UNDP, 2004; Kahn, 2005; Toya and Skidmore 2007; Yonson et al. 2017), supporting the hypothesis that wealthy countries are less likely to suffer impacts from natural disasters (Kellenberg and Mobarak, 2008, Cavallo & Noy, 2011). In this context, Kellenberg and Mobarak (2008) argue that behavioral changes at the micro level in response to increasing income (such as location choice and extent of costly abatement activity) may lead to a nonlinear relationship between aggregate incomes and disaster damages, where the risks increase with income before they decrease. However, Raschky (2008) finds a U-shaped relationship between economic development and economic disaster losses, suggesting that economic development is good protection against natural hazards, but with a diminishing rate.

Schumacher and Strobl (2011) contribute to such discussion by showing theoretically and empirically that the sort of nonlinearity between economic losses caused by natural disasters and income level depends on how exposed are the countries to environmental shocks. Countries that face a high (low) hazard of disasters are likely to experience first decreasing (increasing) losses and then increasing (decreasing) ones with increasing economic development.

The literature has also shown that countries with better institutions experience fewer victims and lower economic losses from natural disasters (Kahn, 2005; Raschky, 2008). Recently, investigating the determinants of disaster fatalities from tropical cyclones in the Philippines, Yonson et al. (2017) find that socioeconomic development and good local governance reduces disaster fatalities, while unplanned urbanization is associated with more fatalities.

The objective of this investigation is to contribute to this literature by providing empirical evidence of a relationship between local development and the impact of natural disasters in the Ceará state by using data from the Damage Assessment Reports from the Civil Defence (Relatório de Avaliação de Danos - AVADAN). Using the same data source, De Oliveira (2019) shows that damages caused by droughts and floods slow down the economic growth of municipalities between 2002 and 2011.[6]

Furthermore, Ceará belongs to the poorest region of Brazil, the Northeast region, and 87% of its territory and 56% of its population are within the great semiarid region.[7] For instance, Ceará has the eighth largest population out of 27 federal unities (i.e., 8.5 million, which is slightly larger than the population of Austria), but only the fifth lowest per capita GDP (US$ 6,652 PPP) and economically comparable to Guatemala (US$ 6,578 PPP).[8] Besides, Ceará has the sixth largest amount of economic losses from natural disasters between 1995 and 2014 in Brazil. These characteristics make Ceará an interesting case study to verify whether the economic development at the municipal level implies a lower vulnerability to environmental shocks.

Our results show that more developed municipalities exhibit a lower proportion of affected people, as well as lower per capita losses caused by natural disasters. Specifically, the study shows that better urban and water supply infrastructure, smaller population density, a higher proportion of own revenues relative to total receipts, and larger income lead to smaller impacts from droughts and floods, which are the main environmental shocks across municipalities in the Ceará state. On the other hand, large public expenditure leads to larger impacts from natural disasters, probably reflecting the inefficiency of municipalities in enabling public policies of prevention and response to natural disasters.

[6] De Lima and Barbosa (2018) show that the 2008 flash floods in the State of Santa Catarina caused a reduction of 7.6% in the GDP per capita of directly affected municipalities in the year of the disaster.
[7] The Brazilian semiarid region is characterized by annual precipitation below 800mm, a dryness index of 0.5 or below, and risk of a drought of at least 60%.
[8] Data on population and GDP can be accessed at www.ibge.gov.br.

However, evidence suggests that economic development in terms of GDP per capita exhibits a U-shaped relationship with the impact of natural disasters. This evidence is aligned with Schumacher and Strobl (2011) who predict that high-hazard countries are more likely to exhibit a U-shaped relationship between wealth and economic impacts of natural disasters because of decreasing returns of public investment in preventive policies. Therefore, the current investigation contributes to the growing literature that has been dedicated to understand how economic development can further contribute to reducing vulnerability of national and subnational governments to natural disasters (Kahn, 2005; Toya and Skidmore, 2007; Peduzzi et al., 2009; Schumacher and Strobl, 2011; Yonson et al., 2017).

The remainder of this study is structured as follows: on Section 2 presents an empirical model, Section 3 describes the data sources, Section 4 analyses the results. Finally, Section 5 concludes the study.

2 Empirical Model

The Intergovernmental Panel on Climate Change (IPCC, 2012) defines disaster risk as “the likelihood over a specified time period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery”.[9]

In this framework, disaster risk means the possibility of adverse effects in the future due to a disaster occurrence, being a combination of physical hazards, vulnerabilities, and exposure

[9] A more general definition is provided by the United Nations International Strategy for Disaster Reduction (UNISDR, 2009), which defines disaster risk as to the potential disaster losses, in lives, health status, livelihoods, assets, and services, which could occur to a particular community or a society over some specified future time period.

(or exposed elements). Based on UNDRO (1980), Cardona (2011) provides the following formulation:

$$Risk = Hazard \times Exposure \times Vulnerability \quad (1)$$

where *Hazard* is defined as "the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources". *Exposure* refers to "the presence (location) of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss, or damage". *Vulnerability* is defined as "the propensity or predisposition to be adversely affected" (IPCC, 2012).

The empirical strategy of this analysis relies on a variation of the generalized multiplicative model of Peduzzi et al. (2009) relative to the equation (1). We model the risk as

$$Risk = CE^{\delta}(V_1^{\beta_1}V_2^{\beta_2} \cdots V_K^{\beta_K})exp^{\theta H} \quad (2)$$

where C is a multiplicative constant, H is the measure of hazard, E is the measure of exposure, and V_K is the Kth measure of vulnerability. Notice that we are assuming that the risk of natural disasters increases exponentially with hazard. Moreover, Peduzzi et al. (2009) assume that if there is no hazard (e.g. no occurrence of cyclones or droughts) the risk of natural disasters is null. In equation (2), we relax this assumption since the measure of hazard is based on the annual precipitation of municipalities.

Taking natural log of equation (2), allows us to measure elasticities regarding the impact of exposure (δ) and vulnerability ($\beta_1, \beta_2, \dots, \beta_k$) on the measure of the natural disaster. A semi-elasticity is obtained regarding the impact of hazard (θ) on the measure of the natural disaster. That is,

$$\ln ND = \alpha + \theta H + \delta \ln E + \sum_{k=1}^{K} \beta_k \ln V_k \qquad (3)$$

where $\alpha = \ln C$. The dependent variable is ND that is the measure of the impact of natural disasters, expressed in terms of the proportion of affected population relative to population size (AP) and disaster losses per capita (DL).

Using a panel data framework to estimate the semi-elasticity and elasticities, we reformulate the equation (3) as follows:

$$\ln ND_{it}^{*} = \alpha + \theta H_{it} + \delta \ln E_{it} + \sum_{i=1}^{k} \beta_i \ln V_{k,it-1} + \varepsilon_{it}$$
$$\ln ND_{it} = \begin{cases} \ln ND_{it}^{*} \; if \; \ln ND_{it}^{*} > 0 \\ 0, \; otherwise \end{cases} \qquad (4)$$

where $i = 1, \ldots, 184$ and $t = 2002, \ldots, 2011$. Lagged vulnerability controls are included in the model in order to prevent reversal causation with natural disaster impact (Schumacher and Strobl, 2011). Moreover, the error term ε_{it} has two components: $\nu_i \sim NID(0, \sigma_\nu^2)$ is the time-invariant individual random effect and $\eta_{it} \sim NID(0, \sigma_\eta^2)$ is the time-varying idiosyncratic random error, which is assumed to be independent of each other.

Another important aspect regarding equation (4) is the fact that the dependent variable is left-censored, once a disaster is recorded by the Civil Defence in Brazil only after notification of the existence of affected people and/or economic losses caused by the environmental shock (MIN, 2007). Thus, the Panel Tobit Model is used to estimate the parameters of the equation (4).

3 Data

3.1 Study area

Ceará is one of the nine states in the Northeast of Brazil with a total area of about 148,886 km² (see Figure 1), in which 87% of its territory is in the great semiarid region of the country. The predominant climate is the hot tropical semi-arid one, which promotes 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 ABOUT HERE]

On average, the population size of municipalities is 46,000 inhabitants. The capital of the State, Fortaleza, has 2.5 million inhabitants according to the 2010 Demographic Census. The service/commerce sector is the main economic activity, responsible for 65% of the total GDP between 2004 and 2011. Manufacturing and agriculture approximately share 14% and 16% of the total output of municipalities. While municipalities of the metropolitan region concentrate most of the value-added of services/commerce and manufacturing, 81% of the value-added of agriculture is generated by the municipalities of the semi-arid region (De Oliveira, 2019).

3.2 Exposure of municipalities to climatic hazards

Given that the semi-arid region lies almost all of Ceará's territory, droughts are expected to be the most frequent climatic event across municipalities. Figure 2 displays the distribution of municipalities based on the deviation of annual precipitation regarding their historical mean of precipitation in the previous 30 years (mean equals to -0.52% and standard deviation of 34.43). Notice that negative deviation is observed for more than 75% of municipalities in 2005, 2007 and 2010. The period between 2004 and 2006 was a prolonged drought period for at least 50% of municipalities in Ceará.

[INSERT FIGURE 2 ABOUT HERE]

On the other hand, rainfall seasons in 2004, 2009 and 2011, led to positive deviation in the annual precipitation for more than two-thirds of municipalities. The positive deviation is more than double the historical mean in some municipalities, which would result in disaster due to excessive rainfall. Thus, a hypothesis to be tested in this study is if these extreme deviations of the level of precipitation regarding the historical mean of municipalities imply in natural disasters, either related to droughts or floods.

Using data from the Damage Assessment Reports of the Civil Defence (Relatório de Avaliação de Danos – AVADAN), De Oliveira (2019) shows that extreme climate events were the main causes of natural disasters in Ceará between 2002 and 2011. Slightly more than two-thirds of disasters were caused by droughts, 76.4%, while the other 22% were due to floods. This evidence is also documented by the Atlas Brasileiro de Desastres Naturais 1991-2012 (CEPED, 2013). Figure 3 shows that almost all municipalities did report damages due to droughts or floods between 2002 and 2011.

[INSERT FIGURE 3 ABOUT HERE]

On average, about 7.2% (SD=11.48) of the population of municipalities was affected by natural disasters, respectively 11.2% (SD=20.63) due to droughts and 3.14% (SD=11.06) due to floods (see Table 1). Figure 4 displays maps of the distribution of municipalities according to the percentage of population affected by droughts and floods.

[INSERT FIGURE 4 ABOUT HERE]

It is worth noting that municipalities with a population affected by droughts may also be affected by floods. This evidence is also observed in Figure 5, which shows the spatial distribution of per capita losses due to droughts and floods. De Oliveira (2019) shows that the average value of per capita losses is R$ 127.22 (SD=881.51), respectively R$ 67.34 (SD=456.10) regarding droughts and R$ 58.50 (SD=757.01) regarding floods.

[INSERT FIGURE 5 ABOUT HERE]

3.3 Vulnerability of municipalities to natural disasters

In this subsection, the objective is to present proxy variables that account for municipality vulnerability to natural disasters. It is important to specifically account for *Susceptibility* and *Lack of Resilience* (IPCC, 2012). Measures of *Susceptibility* include an index of the urban infrastructure of municipalities, based on principal components, that includes schools, health establishments, the fleet of trucks, and the number of firms. All these variables are normalized by the population size of municipalities in order to produce the index that varies from 0 to 100. Similarly, water supply infrastructure is proxied by another index based on principal components that include: number of water pipeline systems serving the municipality, connections with water basin integration axes (so-called, Eixão das Águas), and the number of water dams. De Oliveira (2019) has shown that water supply infrastructure contributes to reducing the impact of natural disasters on the growth rate of the service sector, despite the absence of its mitigating role regarding the agriculture sector. We also include population density as measures of the predisposition of human beings to natural disasters.

In order to account for the *Lack of Resilience*, we include total GDP per capita of municipalities, expenditure per capita, and tax revenue relative to total revenue. Total GDP per capita is our measure of income and captures the differences in the level of economic development across municipalities. Toya and Skidmore (2007) use the output per capita to investigate if the level of development matters to explain the fatalities due to natural disasters across countries. Expenditure per capita measures of the size of municipal government, and may exhibit ambiguous relationships with our measures of natural disaster impact. The authors argue that a large size of government may reflect the inefficiency of the public expending, which would lead to the large impact of natural disasters. On the other hand, a large size of government may reflect the public investment that prevents the impact of natural disasters and helps the population to adapt to environmental adversities. Finally, tax revenue as a proportion of total revenue captures the capacity of the local government of coping with losses due to natural disasters. A high value of this variable indicates greater local effort and effectiveness in revenue generation that leads to greater financial resources for the provision of public goods (Yonson et al., 2017).

3.4 Descriptive statistics

The AVADAN provides information on the affected population (see Figure 4) and losses from disasters (see Figure 5). In order to capture the impact of natural disasters, two measures are assumed in the current study, that is:

$$AP_{it} = \frac{Affected\ Population_{it}}{Population_{it-1}},$$

and

$$DL_{it} = \frac{Disaster\ Losses_{it}}{Population_{it-1}},$$

where AP_{it} is the proportion of the affected population by droughts and floods in municipality i in the year t, and DL_{it} is the per capita losses due to natural disasters of municipality i in the year t. Loayza et al. (2012) used the affected population normalized by population size to measure the impact of natural disasters on economic growth across countries, whereas Toya and Skidmore (2007) use economic damage relative to GDP.[10] De Oliveira (2019) estimates the impact of per capita losses due to natural disasters on the economic growth rate of municipalities in the State of Ceará.

In addition to reporting the descriptive statistics for the dependent variables and the measure of hazard, Table 1 also displays mean and standard deviation regarding the measures of exposure and vulnerability. Relative to exposure, on average, 20.3 thousand people are exposed to natural disasters in the State of Ceará, respectively 12.9 thousand regarding drought and 7.4 due to floods.

[INSERT TABLE 1 ABOUT HERE]

The average score of urban infrastructure is about 26.4, which would be considered a low average score in a range from 0 to 100. Similarly, water supply infrastructure shows an average near 12.7 scores in an interval from 0 to 100. Besides, the average population density is approximately 110 people per Km^2. Tax revenue shares only 3.4% of total revenue, and public expenditure per capita is near R$ 862 (or US$ 619 PPP). The average GDP per capita is R$ 5,149 (or US$ 3,698 PPP). Table A1 in the Appendix provides pairwise correlations among dependent variables and the set of covariates.

4 Results

4.1 Baseline results

Table 2 present the baseline estimates for equation (4), which displays the estimated coefficients and marginal effects of the explanatory variables. Using the 3rd quintile of the distribution of

[10] Fatalities due to natural disasters have been used as the dependent variable in studies that investigate the association between natural disaster impact and economic development within and across countries (Toya and Skidmore, 2007, Yonson, 2017). However, this type of consequence of natural disasters is very infrequent in Ceará (CEPED, 2013), which led us to discard it as a measure of the impact of environmental shocks.

the deviations of annual precipitation regarding the historical mean as the reference category, the estimates show that only the 5th quintile is positively and statistically significant. Municipalities with a deviation of annual precipitation in the 5th quintile of the distribution exhibit, on average, an expected proportion of the affected population by natural disaster increased in 0.19%, and expected disaster losses per capita increased in 0.52% in comparison with municipalities in the 3rd quintile of the distribution. This result implies that the excess of rainfall is more likely to generate a larger disaster impact to municipalities than the lack of rainfall.

In terms of exposure to disasters, the results corroborate the literature (Peduzzi et al., 2009; Yonson et al. 2017) and show a positive relationship with the impact of natural disasters. Estimated marginal effects show that an increase of exposed population to natural disasters in 1% leads to a variation in the expected proportion of affected population in approximately 0.86%, and 1.5% relative to the expected disaster losses per capita. It is worth noting that this estimated effect of exposure takes into account the population who were exposed to both droughts and floods. In the next subsection, this effect is estimated separately for these two types of environmental shocks.

[INSERT TABLE 2 ABOUT HERE]

Lagged vulnerability controls are important predictors for the impact of natural disasters in municipalities of the State of Ceará as judged by the joint significant test. For instance, an increase of 1% in the index of urban infrastructure would reduce the impact of natural disasters in 0.17% regarding the expected proportion of the affected population and 0.25% in terms of expected disaster losses per capita. Similar results are observed for water supply infrastructure. An increase of 1% in the index would lead to a drop in the expected proportion of the affected population by 0.11% and near 0.18% relative to the expected disaster losses per capita. These results support the role played by the infrastructure in adaptation for climate disaster (Hallegatte, 2009), which has been the main public policy of drought preparedness in the Ceará state (Gutiérrez et al., 2014).

However, the impact of natural disasters is negatively associated with population density. An increase in population density by 1% would result in a reduction of 0.39% in the expected proportion of the affected population and 0.67% in the expected disaster losses per capita. This evidence may reflect the better (worse) capacity of response and adaptation of high (low) population density municipalities to natural disasters, despite the population density has been widely treated by the literature as a risk factor of natural disasters (Birkmann, 2007). Cross (2001), for instance, argues that small cities and rural communities — which by definition have a lower population density — are more vulnerable to disasters, since large cities and megacities often have considerable resources for dealing with hazards and disasters.

In addition, Table 2 also shows that the public finance of municipalities matters to predict the magnitude of the impact of natural disasters in the State of Ceará. Municipalities that increase the participation of their tax revenue relative to the total revenue by 1% would reduce the proportion of affected population by 0.16% and the expected disaster losses per capita by 0.27%. This evidence corroborates Toya and Skidmore (2007) who show that the government size may reflect inefficiencies that lead to a large impact of natural disasters. On the other hand, an increase of 1% in the municipality expenditure per capita would result in an increase of 0.44% in the expected proportion of the affected population and 0.96% in the expected disaster losses per capita. Yonson et al. (2017) find that a variation of one percentage point in the proportion of tax revenue relative to total GDP would reduce the fatalities due to cyclones in the Philippines by 0.38%.

Results in Table 2 show that the income of municipalities is negatively associated with the magnitude of the impact of natural disasters in the State of Ceará, which corroborates the specialized literature (Toya and Skidmore, 2007; Peduzzi et al., 2009; Yonson et al., 2017). An increase of 1% in the average income would reduce the expected proportion of affected population by 0.52% and the expected disaster losses per capita by 0.64%. Our elasticities are in line with empirical evidence within and across countries. Toya and Skidmore show that elasticities for the number of fatalities due to natural disasters regarding GDP per capita are near -0.15, and -0,12 relative to disaster losses as a fraction of the total GDP across countries. Yonson et al. (2017) estimate income elasticity near -1.13 regarding total fatalities due to cyclones in the Philippines normalized by population size. Peduzzi et al. (2009) find elasticities between the number of fatalities and GDP per capita across countries of -0.53 for cyclones, -4.54 for droughts, -0.70 in case of floods. Therefore, the evidence in Table 2 shows that the level of economic development of a municipality is an important predictor for the impact of natural disasters.

5.2 Testing additional hypotheses

This subsection aims to verify additional hypotheses related to the model (4). First of all, it is important to investigate whether the effect of the exposed population on the expected impact of natural disasters differs regarding the type of natural disaster. Furthermore, it is tested whether the relationship between the impact of natural disasters and the income level of municipalities is nonlinear as predicted by Schumacher and Strobl (2011).

Differences in the effect of exposed population due to droughts and floods

De Oliveira (2019) shows that reported disasters due to droughts are more than three times the number of reported disasters due to floods in the State of Ceará between 2002 and 2011. However, there is no substantial difference in the average affected population regarding these two types of natural disaster, but the average losses caused by floods is almost three times larger than the average losses caused by droughts. Thus, an immediate question to be answered is whether the exposed population to droughts have a different effect on the expected impact of natural disasters when compared with the exposed population to floods.

Table 3 replicates Table 2, but using the natural log of population size multiplied by the number of a specific reported disaster. Since droughts and floods are the main natural disasters reported by municipalities to the Civil Defence in the State of Ceará, we measure the effect of the exposed population to these two types of environmental shocks on the expected impact of natural disasters. The test of difference in the coefficients suggests that the effect of the exposed population to drought on the expected proportion of the affected population is not statistically different from the effect of the exposed population to floods. In terms of marginal effects, an increase of 1% in the exposed population to droughts would raise the proportion of the affected population in 0.71%, while the same variation in the exposed population to floods would increase the impact of natural disasters in terms of affected population by 0.75%.

[INSERT TABLE 3 ABOUT HERE]

Nonetheless, the effect of the exposed population concerning droughts and floods is statistically different when the impact of natural disasters is measured in terms of disaster losses per capita. The estimated marginal effects show that an increase of 1% in the exposed population to droughts would raise the expected disaster losses per capita in approximately 1.1%, while the same variation in the exposed population to floods would increase the impact of natural disasters in terms of disaster losses per capita by 1.4%. Although floods are much less frequently reported by municipalities to the Civil Defence than droughts, their exposure effect generates a larger expected impact in terms of disaster losses than droughts. These findings corroborate the evidence in De Oliveira (2019).

Nonlinearity in income effects

Table 2 shows that the relationship between income and the impact of natural disasters across municipalities in the State of Ceará follows a linear form, similarly to within- and cross-country studies (Toya and Skidmore, 2007; Peduzzi et al., 2009; Yonson et al., 2017). However, Schumacher and Strobl (2011) predict that high hazard countries are likely to exhibit a U-shaped relationship between wealth and economic losses, while low hazard countries are likely to have an inversely U-shaped one.

Since Ceará is one of the most hazardous states in Brazil (CEPED, 2016), and belongs to one of the risky regions (Northeast Brazil) in the world due to the ongoing climate change (IPCC, 2012), it is important to investigate whether the relationship between natural disaster impact and income is nonlinear. In order to perform such analysis, estimations in Table 2 are re-done with the inclusion of the squared natural log of GDP per capita as an additional explanatory variable. The likelihood-ratio test (LR test) is computed as a way to compare the linear and nonlinear specification of income in the right-hand side of equation (4).

In Table 4, the LR test shows that the restricted and unrestricted models (i.e. models with the linear and nonlinear form of income) are not nested, which suggests that the quadratic form of income is the appropriate form to interpret its relationship with the natural disaster impact. The estimated parameters show a U-shaped relationship between income and the measures of natural disaster impact. The low turning point of the measures of natural disaster impact concerning the natural log of the lagged GDP per capita is at 9.3, which is slightly above the mean value of the covariate of interest (8.43).

[INSERT TABLE 4 ABOUT HERE]

This evidence is aligned with the predictions of Schumacher and Strobl (2011). The authors argue that high hazard countries are likely to undertake prevention expenditure even at very low levels of wealth, and experience decreasing losses with increasing wealth if the marginal benefits from prevention expenditure outweigh the costs. In this case, losses due to natural disasters may decrease with economic development. However, if the potential for prevention expenditure is limited, then marginal benefits from further prevention expenditure may be decreasing. According to the authors, this effect should be more significant for high hazard countries than for low hazard ones, which leads to increasing losses with higher levels of economic development.

This scenario appropriately fits what happens in the State of Ceará and, probably, with all Northeast region. Municipalities have a very limited investment capacity on natural disaster prevention and mitigation, mostly depending on public investment from federal and state governments (Gutiérrez et al., 2014). As far as these municipalities reach higher levels of development, their vulnerability to natural disasters is reduced due to the increase in local investment regarding education, urbanization, sanitation, etc. However, larger investment in natural disaster prevention, which depends on federal and state funds (e.g., access to water), may not fully prevent municipalities from severe natural disasters. This is worrisome, once these municipalities may face severe consequences from global warming in the near future. Thus, it is expected that high levels of economic development may be associated with larger natural disaster impacts.

5 Conclusion

The current study presents evidence that local development is an important driving factor for the vulnerability of municipalities in the State of Ceará to natural disasters, i.e., droughts and floods. Provision of urban and water supply infrastructure, improvement in the tax collection and on the efficiency of public expenditure of municipalities can help them to reduce the impact of natural disasters, measured by the affected population and total losses due to droughts and floods. These results are very informative for policymakers who aim to improve the capacity of adaptation of municipalities to environmental shocks. Besides, the impact of disasters is, on average, larger in lower population density municipalities, probably reflecting the worse capacity of response and adaptation of such density municipalities to natural disasters (Cross, 2001).

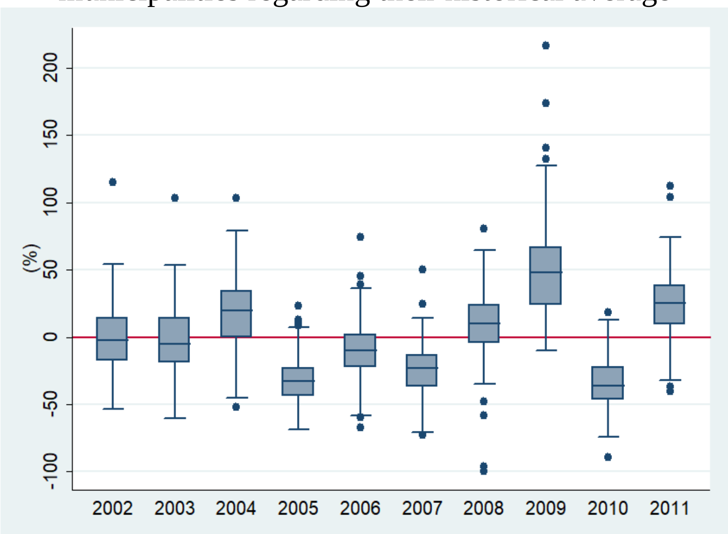
In addition, economic development, measured in terms of GDP per capita, exhibits a U-shaped relationship with the impact of natural disasters. This is not an unexpected result, once Ceará is one of the hazardous states in Brazil (CEPED, 2013; 2016). In light of Schumacher and Strobl (2011), the impact of natural disasters can be reduced with improvements from municipality income that enables more investment in disaster preparedness. However, such investment may exhibit decreasing returns at high levels of income, leading to large impacts of natural disasters. Thus, evidence in this investigation contributes to understanding how economic development can reduce the vulnerability of municipalities to natural disasters (Kahn, 2005; Toya and Skidmore, 2007; Peduzzi et al., 2009; Schumacher and Strobl, 2011; Yonson et al., 2017).

FIGURES

Figure 1: Map of Ceará State, Northeast, Brazil

Source: De Oliveira (2019).

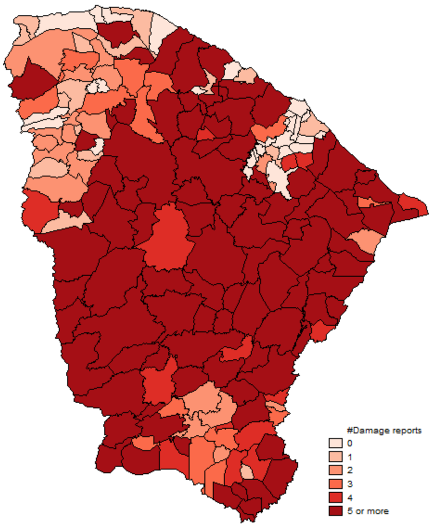
Figure 2: Normalized deviation of annual precipitation of municipalities regarding their historical average



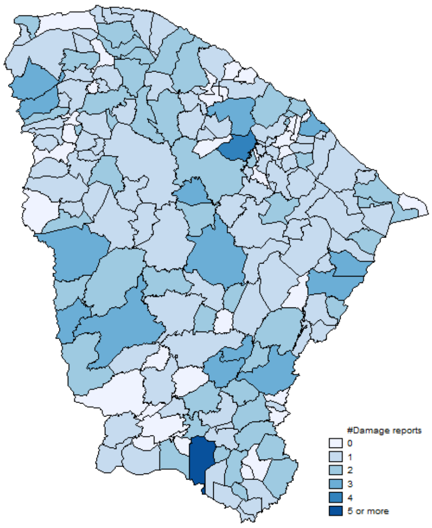
Source: Fundação Cearense de Meteorologia e Recursos Hídricos - FUNCEME.

Figure 3: Spatial distribution of damage reports related to natural disasters in Ceará between 2002 and 2011

(a) Damage reports related to droughts



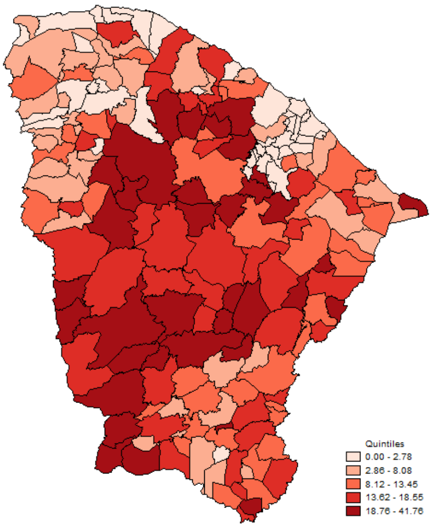
(b) Damage reports related to floods



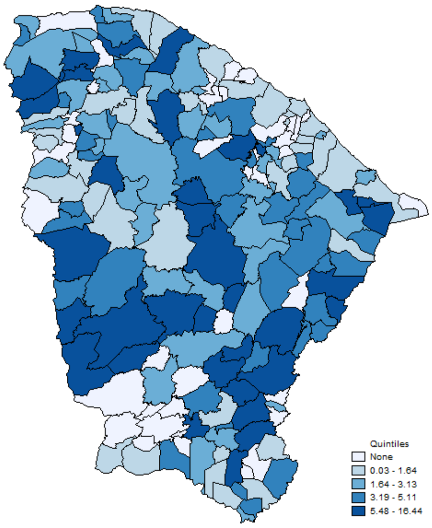
Source: Elaborated by authors.

Figure 4: Spatial distribution of population affected by natural disasters in Ceará between 2002 and 2011

(a) Population affected by droughts



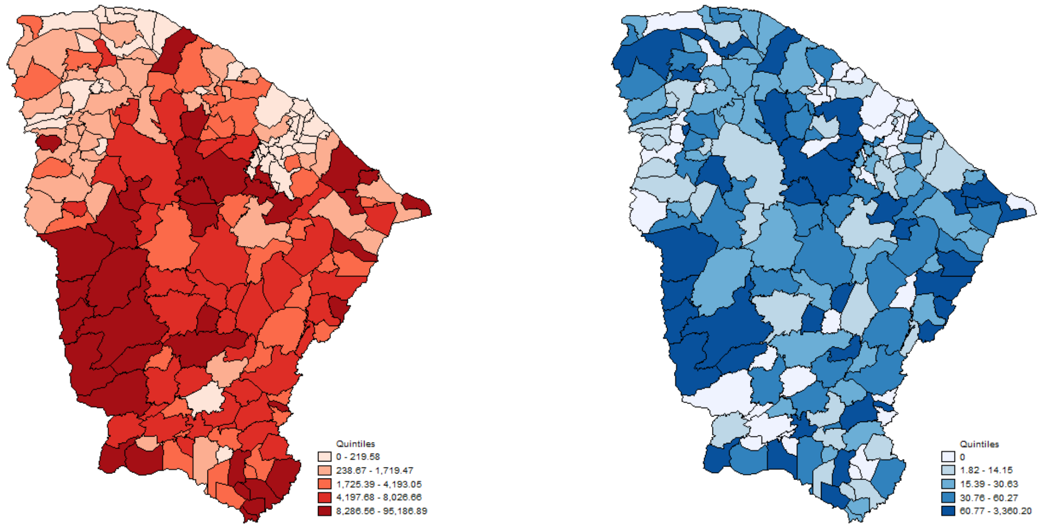
(b) Population affected by floods



Source: Elaborated by authors.

Figure 5: Spatial distribution of per capita losses due to natural disasters in Ceará between 2002 and 2011

(a) Per capita losses due to droughts (b) Per capita losses due to floods



Source: Elaborated by authors.

TABLES

Table 1: Descriptive statistics

	Absolute values		Natural log	
	Mean	**SD**	**Mean**	**SD**
Dependent variables				
Affected population relative to population (%)	8.017	11.922	1.177	1.459
Total losses per capita (R$)	119.016	846.143	1.857	2.410
Hazard controls				
Deviation of annual precipitation from the historical mean (%)	-0.524	34.431	-	-
Exposure				
Exposed population x disaster event	20,259	83,603	9.243	1.048
Droughts	12,896	31,899	9.041	0.942
Floods	7,363	77,543	8.734	0.657
Vulnerability controls				
Urban infrastructure index	26.42	15.95	3.082	0.623
Water supply infrastructure	12.71	15.67	1.820	1.351
Population density (pop./Km²)	110	575.93	3.723	0.939
Tax revenue relative to total revenue (%)	3.41	2.62	1.080	0.497
Municipal expenditure per capita (R$)	862.26	275.70	6.673	0.315
GDP per capita (R$)	5,148.76	3,128.97	8.431	0.374
Observations				**1,656**

Note. Own elaboration.

Table 2: Baseline results from panel Tobit model with random effects

	ln(Affected Pop./ Pop.)		ln(Disaster Losses/Pop.)	
	Coefficients	*Marginal Effects*	*Coefficients*	*Marginal Effects*
Hazard controls				
1st quintile of the deviation of annual precipitation	0.024	0.010	-0.074	-0.031
	(0.139)	(0.059)	(0.228)	(0.095)
2nd quintile of the deviation of annual precipitation	0.045	0.019	-0.234	-0.098
	(0.128)	(0.054)	(0.208)	(0.088)
4th quintile of the deviation of annual precipitation	0.135	0.057	0.229	0.096
	(0.142)	(0.060)	(0.231)	(0.098)
5th quintile of the deviation of annual precipitation	0.438***	0.186***	1.237***	0.518***
	(0.152)	(0.068)	(0.246)	(0.122)
Exposure control				
ln(Population x reported natural disaster)	2.037***	0.864***	3.501***	1.466***
	(0.070)	(0.108)	(0.123)	(0.187)
Lagged vulnerability controls				
ln(Urban infrastructure)	-0.406***	-0.172***	-0.596***	-0.250***
	(0.122)	(0.056)	(0.201)	(0.090)
ln(Water supply infrastructure)	-0.262***	-0.111***	-0.418***	-0.175***
	(0.056)	(0.027)	(0.095)	(0.045)
ln(Population density)	-0.926***	-0.392***	-1.607***	-0.673***
	(0.105)	(0.065)	(0.184)	(0.113)
ln(Tax revenue relative to total revenue)	-0.372***	-0.158***	-0.646***	-0.271***
	(0.113)	(0.052)	(0.184)	(0.084)
ln(Municipal expenditure per capita)	1.037***	0.440***	2.288***	0.958***
	(0.245)	(0.117)	(0.398)	(0.206)
ln(GDP per capita)	-1.231***	-0.522***	-1.522***	-0.637***
	(0.248)	(0.123)	(0.415)	(0.191)
Joint significant test (Chi-square)				
Hazard controls	9.177*		36.076***	
Lagged vulnerability controls	258.330***		233.053***	
RE Tobit versus Pooled Tobit				
LR test *(Chi-square)*	116.26***		156.15***	
Likelihood ratio	2062.375***		2013.498***	
Loglikelihood	-1327.835		-1783.772	
N	1,656		1,656	

Note. Standard errors are in parentheses. Dummy variables for years are included in the estimations. *p-value<0.1, **p-value<0.05, and ***p-value<0.01.

Table 3: Results from panel Tobit model with random effects using exposed population to droughts and floods

	ln(Affected Pop./ Pop.)		ln(Disaster Losses/Pop.)	
	Coefficients	*Marginal Effects*	*Coefficients*	*Marginal Effects*
Hazard controls				
1st quintile of the deviation of annual precipitation	0.147	0.063	0.178	0.075
	(0.148)	(0.064)	(0.237)	(0.101)
2nd quintile of the deviation of annual precipitation	0.114	0.048	-0.084	-0.036
	(0.137)	(0.059)	(0.218)	(0.092)
4th quintile of the deviation of annual precipitation	0.170	0.072	0.217	0.092
	(0.151)	(0.066)	(0.241)	(0.103)
5th quintile of the deviation of annual precipitation	0.500***	0.212***	1.206***	0.511***
	(0.163)	(0.080)	(0.259)	(0.138)
Exposure control				
ln(Population x reported droughts)	1.679***	0.713***	2.637***	1.118***
	(0.063)	(0.139)	(0.106)	(0.189)
ln(Population x reported floods)	1.764***	0.749***	3.203***	1.358***
	(0.076)	(0.147)	(0.122)	(0.229)
Lagged vulnerability controls				
ln(Urban infrastructure)	-0.377***	-0.160***	-0.544***	-0.231**
	(0.119)	(0.059)	(0.192)	(0.090)
ln(Water supply infrastructure)	-0.197***	-0.084***	-0.286***	-0.121***
	(0.051)	(0.027)	(0.085)	(0.041)
ln(Population density)	-0.829***	-0.352***	-1.440***	-0.611***
	(0.096)	(0.079)	(0.161)	(0.122)
ln(Tax revenue relative to total revenue)	-0.363***	-0.154***	-0.646***	-0.274***
	(0.115)	(0.057)	(0.184)	(0.090)
ln(Municipal expenditure per capita)	1.090***	0.463***	2.102***	0.891***
	(0.247)	(0.137)	(0.396)	(0.223)
ln(GDP per capita)	-1.034***	-0.439***	-1.202***	-0.510***
	(0.245)	(0.134)	(0.397)	(0.188)
Joint significant test (Chi-square)				
Hazard controls	10.250		29.369	
Lagged vulnerability controls	243.354		230.326	
Test of differences in coefficients				
Exposure: Droughts versus Floods	1.310		22.386***	
RE Tobit versus Pooled Tobit				
LR test *(Chi-square)*	79.52***		105.95***	
Likelihood ratio	1913.283***		1865.934***	
Loglikelihood	-1402.381		-1857.553	
N	1,656		1,656	

Note. See notes to Table 2 about the dependent variable and covariates. Standard errors are in parentheses. *p-value<0.1, **p-value<0.05, and ***p-value<0.01.

Table 4: Results from panel Tobit model with random effects, accounting for nonlinearities in income effects

	ln(Affected Pop./ Pop.)		**ln(Disaster Losses/Pop.)**	
	Coefficients	*Marginal Effects*	*Coefficients*	*Marginal Effects*
Hazard controls				
1st quintile of the deviation of annual precipitation	0.033	0.014	-0.072	-0.030
	(0.138)	(0.059)	(0.227)	(0.095)
2nd quintile of the deviation of annual precipitation	0.052	0.022	-0.234	-0.098
	(0.127)	(0.054)	(0.208)	(0.088)
4th quintile of the deviation of annual precipitation	0.136	0.058	0.224	0.094
	(0.141)	(0.060)	(0.230)	(0.097)
5th quintile of the deviation of annual precipitation	0.425***	0.180***	1.217***	0.510***
	(0.151)	(0.067)	(0.245)	(0.123)
Exposure control				
ln(Population x reported natural disaster)	2.049***	0.869***	3.515***	1.474***
	(0.070)	(0.099)	(0.122)	(0.197)
Lagged vulnerability controls				
ln(Urban infrastructure)	-0.338***	-0.143***	-0.516**	-0.216**
	(0.124)	(0.055)	(0.203)	(0.090)
ln(Water supply infrastructure)	-0.271***	-0.115***	-0.429***	-0.180***
	(0.056)	(0.027)	(0.095)	(0.046)
ln(Population density)	-0.973***	-0.413***	-1.670***	-0.700***
	(0.107)	(0.064)	(0.187)	(0.120)
ln(Tax revenue relative to total revenue)	-0.387***	-0.164***	-0.670***	-0.281***
	(0.113)	(0.051)	(0.183)	(0.085)
ln(Municipal expenditure per capita)	1.090***	0.462***	2.362***	0.990***
	(0.243)	(0.116)	(0.396)	(0.212)
ln(GDP per capita)	-18.700***	-7.929***	-24.008***	-10.065***
	(5.337)	(2.421)	(8.731)	(3.888)
ln(GDP per capita)²	1.005***	0.426***	1.294***	0.542**
	(0.306)	(0.138)	(0.501)	(0.222)
Joint significant test (Chi-square)				
Hazard controls	8.645*		35.286***	
Lagged vulnerability controls	263.408***		238.301***	
Likelihood ratio test (Chi-square)				
RE Tobit versus Pooled Tobit	123.55***		161.62***	
Linear form versus nonlinear form	10.633***		6.491***	
Likelihood ratio	2073.009***		2019.989***	
Loglikelihood	-1322.518		-1780.526	
N	1,656		1,656	

Note. Standard errors are in parentheses. Dummy variables for years are included in the estimations. *p-value<0.1, **p-value<0.05, and ***p-value<0.01.

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Appendix

Table A1: Pairwise correlations

	lnAP	**lnDL**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**lnE**	**lnEd**	**lnEf**	**lnI**	**lnH**	**lnPD**	**lnTR**	**lnGE**	**lnGDP**
lnAP	1															
lnDL	0.85***	1														
Q1	0.13***	0.09*	1													
Q2	0.08***	0.01	-0.25***	1												
Q3	-0.08***	-0.11***	-0.25***	-0.25***	1											
Q4	-0.12***	-0.12***	-0.25***	-0.25***	-0.25***	1										
Q5	-0.02***	0.12***	-0.25***	-0.25***	-0.25***	-0.25***	1									
lnE	0.69***	0.67***	0.11***	0.07***	-0.05**	-0.10***	-0.03	1								
lnEd	0.61***	0.45***	0.21***	0.16***	0.00	-0.13***	-0.24***	0.80***	1							
lnEf	0.26***	0.45***	-0.13***	-0.13***	-0.07***	0.05***	0.28***	0.50***	-0.09***	1						
lnI	-0.07***	-0.06**	0.06**	-0.02	0.01	-0.01	-0.04	0.19***	0.13***	0.12***	1					
lnH	0.12***	0.13***	0.00	0.00	0.00	0.02	-0.02	0.24***	0.20***	0.10***	0.06**	1				
lnPD	-0.29***	-0.25***	0.01	-0.02	0.00	0.00	0.01	-0.11***	-0.17***	0.04*	0.39***	-0.26***	1			
lnTR	-0.07***	-0.07***	0.01	-0.02	0.02	-0.01	0.00	0.10***	0.06**	0.08***	0.35***	0.02	0.26***	1		
lnGE	-0.17***	-0.11***	-0.10***	-0.11***	-0.04	0.04*	0.20***	-0.31***	-0.33***	-0.03	-0.05**	-0.13***	-0.02	0.01	1	
lnGDP	-0.16***	-0.10***	0.01	-0.07***	-0.02	-0.01	0.09***	0.03	-0.05*	0.12***	0.57***	-0.03	0.52***	0.45***	0.25***	1

Note. The list of variables includes: lnAP = natural log of the proportion of affected population relative total population size; lnDL = natural log of total losses per capita; lnE = natural log of exposed population to natural disasters; lnEd = natural log of exposed population to droughts; lnEf = natural log of exposed population floods; Q1 = I(1st quintile of the distribution of the deviation of annual precipitation); Q2 = I(2nd quintile of the distribution of the deviation of annual precipitation); Q3 = I(3rd quintile of the distribution of the deviation of annual precipitation); Q4 = I(4th quintile of the distribution of the deviation of annual precipitation); Q5 = I(5th quintile of the distribution of the deviation of annual precipitation); lnI = natural log of the index of urban infrastructure; lnH = natural log of the index of water supply infrastructure; lnPD = natural log of population density; lnTR = natural log of the proportion of tax revenue relative to total revenue; lnGE = natural log of the municipal government expenditures per capita; lnGDP = natural log of municipal GDP per capita.

*p-value<0.1, **p-value<0.05, and ***p-value<0.01.