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LOCAL DEVELOPMENT AND NATURAL DISASTERS IN NORTHEAST BRAZIL: THE CASE OF DROUGHTS AND FLOODS IN STATE OF CEARÁ

FORTALEZA

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Dissertação apresentada ao Programa de Pós-Graduação em Economia da Universidade Federal do Ceará – CAEN/UFC, como requisito parcial para a obtenção do Título de Mestre em Economia.

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Aprovada em ____/____/______.

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Aos meus pais, Moézio e Francisca, com amor e gratidão

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RESUMO

O objetivo desta investigação é contribuir com evidências empíricas da relação entre o desenvolvimento local e o impacto de desastres naturais no estado do Ceará, utilizando dados do Relatório de Avaliação de Danos (AVADAN). Os resultados mostram que municípios mais desenvolvidos apresentam menor proporção de pessoas afetadas, bem como menores perdas per capita causadas por desastres naturais. Especificamente, o estudo mostra que uma melhor infraestrutura urbana e de abastecimento de água, menor densidade populacional, maior proporção de receitas próprias e maior nível de renda levam a impactos menores de secas e inundações, que são os principais choques ambientais no estado do Ceará. No entanto, a relação entre o desenvolvimento econômico em termos de PIB per capita e o impacto de desastres naturais entre os municípios exibe uma relação em forma de U, provavelmente refletindo os retornos decrescentes de políticas preventivas em regiões de alto risco, conforme previsto na literatura. Esta evidência não é uma surpresa, visto que quase a totalidade do território do Ceará está na região semiárida.

Palavras-chaves: Desastres Naturais. Desenvolvimento Local. Ceará. Brazil.

ABSTRACT

The objective of this investigation is to provide empirical evidence of the relationship between local development and the impact of natural disasters in the State of Ceará by using data from the Damage Assessment Reports from the Civil Defence (Relatório de Avaliação de Danos - AVADAN). The results show that more developed municipalities exhibit a lower proportion of affected people, as well as lower per capita losses caused by natural disasters. The study specifically shows that better urban and water supply infrastructure, smaller population density, higher proportion of own revenues and larger income lead to smaller impacts from droughts and floods, which are the main environmental shocks in the State of Ceará. However, economic development in terms of GDP per capita exhibits a U-shaped relationship with the impact of natural disasters across municipalities, probably reflecting the decreasing returns of preventive policies in high hazard regions as predicted in the literature. This evidence does not come as a surprise, since almost all of Ceará's territory is in the semi-arid region.

Keywords: Natural Disasters. Local Development. Ceará. Brazil.

LIST OF FIGURES

LIST OF TABLES

CONTENTS

1 INTRODUCTION

The incidence of natural disasters has caused devastating impacts on social and economic development. In Brazil, a developing country highly exposed to climatic disasters, there were 38,996 records of natural disasters with 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 between 1995 and 2014 (CEPED, 2016).[1] In addition, the negative prognoses on climate change tend to further accentuate these impacts in Brazil, opening space for discussions focused on the risk context, before the disaster materializes (IPCC, 2012; PBMC, 2015).

The definition of disaster risk reflects the concept of disasters as the result of continuously present risk conditions, which comprises different types of potential losses that are difficult to quantify. However, with knowledge of prevailing dangers and patterns of population and socioeconomic development, disaster risk can be assessed and mapped, at least in broad terms (UNISDR, 2009). The occurrence of natural disasters is always preceded by the existence of specific physical and social conditions that are generally referred to it as disaster risk (Wisner et al., 2004, UNISDR, 2009, 2011). In this sense, the usual formulation of disaster risk is associated to 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 human society. For instance, Zhou et al. (2015) analyzed the level of relative risk of major natural events in China and found out 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.

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 idea that higher income

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

levels allow countries to mitigate the risk of disasters (Kellenberg and Mobarak, 2008, Cavallo & Noy, 2011). In this context, Kellenberg and Mobarak (2008) argue that "micro-behavioral changes" in response to increased income can lead to a nonlinear relationship between aggregate income and disaster damage by increasing aggregate exposure, where risks increase with income, before being reduced. This result follows in agreement with Raschky (2008), who suggests a nonlinear relationship between the economic development and the losses by disasters. The author also shows that the institutional structure of a country is a determining factor of vulnerability and disaster fatalities. Schumacher and Strobl (2011) show theoretically and empirically that the sort of nonlinearity between economic losses caused by natural disasters and income level depends on how exposed the countries are to the natural disasters.

Recently, Yonson et al. (2017) found that tropical cyclone-induced fatalities in the Philippines are more influenced by socioeconomic conditions and population exposure than by the actual risk event itself. The authors argue that good local governance is associated with fewer disaster-related fatalities, where increasing efficiency in local revenue generation means greater capacity to provide public goods and services. This is associated with the results of Kahn (2005) which show that countries with higher levels of democracy and better institutions experience fewer deaths caused by earthquake. The study emphasizes that democratic countries adopt actions that diminish the adverse effects of such phenomena.

The objective of this investigation is to contribute to this literature by providing empirical evidence of the relationship between local development and the impact of natural disasters in the State of Ceará by using data from the Damage Assessment Reports from the Civil Defence (Relatório de Avaliação de Danos - AVADAN). Recently, De Oliveira (2019) has shown that damages caused by natural disasters reduce the growth rate of the output per capita across municipal economies in the State of Ceará between 2002 and 2011. While damage due to droughts mainly affects the performance of economic growth in the agriculture sector, damages caused by floods slow down output growth of the services sector. However, human and economic losses are likely to depend on the development level of the affected area (Toya and Skidmore, 2007).

Furthermore, Ceará belongs to the poorest region of Brazil, the Northeast region, and 87% of its territory and 56% of its population are situated in the great semiarid region.[2] For instance, Ceará has the 8th largest population out of 27 federal unities (i.e., 8.5 million, which

[2] 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%.

is slightly larger than the population of Austria), but only the 22th per capita GDP (US$ 6,652 PPP) and economically comparable to Guatemala (US$ 6,578 PPP).[3] Besides, Ceará is the 6th Brazilian state with the highest losses due to natural disasters, and the 2nd in the Northeast region. Thus, the economic vulnerability and the high exposure of the State of Ceará to environmental shocks leads us to an immediate question: does better economic development of municipalities imply less 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. The study specifically shows that better urban and water supply infrastructure, smaller population density, higher proportion of own revenues, and larger incomer lead to smaller impacts from droughts and floods, which are the main environmental shocks across municipalities in the State of Ceará. On the other hand, large public expenditure leads to larger impacts from natural disasters, probably reflecting the inefficiency of municipalities in enabling public policies that are preventive and responsive to natural disasters.

However, evidence suggests that economic development in terms of GDP per capita exhibit 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 reduce vulnerability of national and subnational governments of 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: the section 2 presents a standard framework about the risk of natural disasters, section 3 describes the data sources, section 4 presents the empirical strategy, and section 5 analyses the results. Finally, section 6 concludes the study.

[3] Data on population and GDP can be accessed at www.ibge.gov.br.

2 MEASURING THE RISK OF NATURAL DISASTER

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".[4]

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

$$Risk = Hazard \times Exposure \times Vulnerability \tag{1}$$

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).

Hazard implies a threat or potential for adverse effects, however it doesn't imply the physical event itself (Cardona, 1986, 1996, 2011; Smith, 1996; Tobin and Montz, 1997; Lavell, 2003; Hewitt, 2007). It also has varying degrees of severity and intensity (Wisner et al., 2004), being partly determined by environmental degradation and human intervention in natural ecosystems (Lavell, 1996, 1999a). Moreover, hazard events can only cause damages and losses if population and economic resources are exposed to these events (Cardona, 1990; UNISDR, 2004, 2009b). Thus, public policy focused on land use and territorial planning play a central role on disaster risk reduction (Lavell, 2003; IPCC, 2012).

Although *Exposure* is not a sufficient condition of disaster risk, it is necessary to be exposed to become vulnerable to an extreme event (IPCC, 2012). *Vulnerability* arises as a key

[4] A more general definition is provided by the United Nations International Strategy for Disaster Reduction (UNISDR, 2009), which defines disaster risk as 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.

factor for disaster risk, once it can interact with a hazard event to generate risk (Lavell, 2003; Cannon, 2006; Cutter et al., 2008). It is directly related to the capacity of anticipating, coping with, resisting, and recovering from adverse effects of a hazard event (Wisner et al., 2004). Besides, it is a result of diverse historical, social, economic, political, cultural, institutional, natural resource, and environmental conditions and processes (IPCC, 2012). Different levels of vulnerability will lead to differential levels of damage and loss under similar conditions of exposure to physical events of a given magnitude (Dow, 1992; Wisner et al., 2011).

Although *Vulnerability* can be analyzed under different frameworks[5], there are two important driving factors that are consensus for specialists in disaster risk management and climate change adaptation, that are: *Susceptibility* and *Lack of Resilience*. *Susceptibility* (i.e. fragility in disaster risk management, or sensitivity in climate change adaptation) means physical predisposition of human beings, infrastructure, and environment to be affected by a dangerous phenomenon. It occurs due to lack of resistance and predisposition of society and ecosystems to suffer harm as a consequence of intrinsic and context conditions, making it plausible that such systems once impacted will collapse or experience major harm and damage due to the influence of a hazard event. *Lack of Resilience* (in disaster risk management, or lack of coping/adaptive capacity in climate change adaptation) refers to limitations in access to and mobilization of the resources of the human beings and their institutions, and incapacity to anticipate, adapt, and respond in absorbing the socio-ecological and economic impact (IPCC, 2012). Based on this framework, we present the data source and the empirical model to further investigate the drivers of natural disasters across municipalities in the State of Ceará.

5 According to IPCC (2012), there are at least four approaches dedicated to understand *Vulnerability* in the context of disaster risk and its causes. The first approach is the Pressure and Release (PAR) Model (Blaikie et al. 1994, 1996; Wisner et al., 2004) that emphasizes the social conditions and root causes of exposure more than the hazard as generating unsafe conditions. In this approach, the political economy of resources and political power are mediators of local vulnerability to disasters. The second approach is the Social Ecology Perspective (Hewitt and Burton, 1971; Turner et al., 2003a,b) that focuses on the ability of societies to transform nature and also implications of changes in the environment for social and economic system. In this framework, the coupling processes and the interactions between societies and nature are central elements to understand exposure and susceptibility to disasters. The third line of research refers to Holistic Perspectives that are dedicated to differentiate exposure, susceptibility and societal response capacities as causes of factors of *Vulnerability* (Cardona, 2011; Birkmann, 2006b; Carreño et al., 2007b). This approach argues that *Vulnerability* is dynamic and is the main driver and determinant of current and future risk. The fourth framework is based on the Climate Change Adaptation, led by the Intergovernmental Panel on Climate Change defines vulnerability as a function of exposure, sensitivity, and adaptive capacity (McCarthy et al., 2001; Brooks, 2003; K. O'Brien et al., 2004a; Füssel and Klein, 2006; Füssel, 2007; G. O'Brien et al., 2008), differing of the view of disaster risk management by considering the magnitude and frequency of potential hazard events as one of the dimension of *Vulnerability* to climate change.

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 are 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).

Figure 1: Map of Ceará State, Northeast, Brazil

Source: De Oliveira (2019).

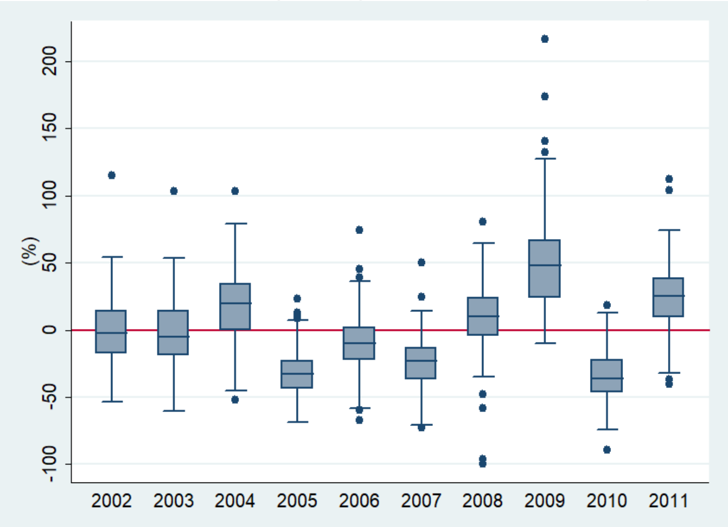
On average, population size of municipalities is 46,000 inhabitants. The capital of the State, Fortaleza, has 2.5 million inhabitants according to the 2010 Demographic Census. The service/commerce sector is the main economic activity, responsible for 65% of total GDP between 2004 and 2011. Manufacturing 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.

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



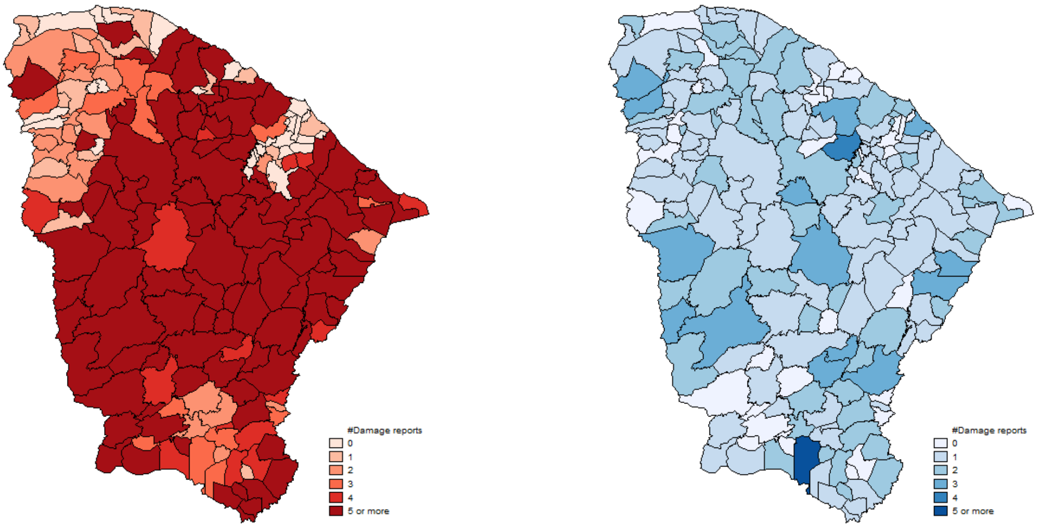
Source: Fundação Cearense de Meteorologia e Recursos Hídricos - FUNCEME.

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 of the historical mean in some municipalities, which would result in disaster due to excessive rainfalls. 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 implies 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 other 22% were due to floods. This evidence is also documented by the Atlas Brasileiro de Desastres Naturais 1991-2012 (Centro Universitário de Estudos e Pesquisas em Desastres, 2013). Figure 3 shows that almost all municipalities did report damages due to droughts or floods between 2002 and 2011.

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

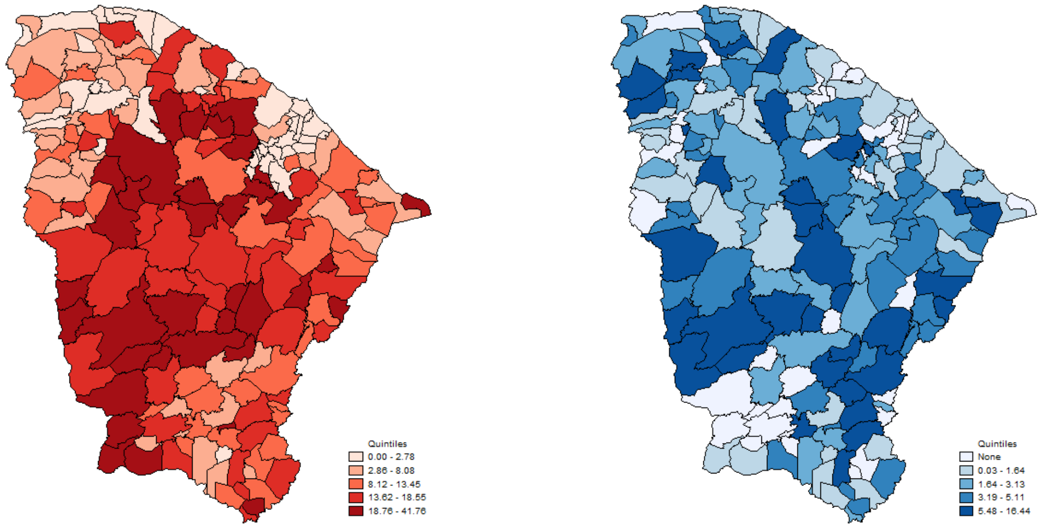


Source: Elaborated by authors.

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.

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

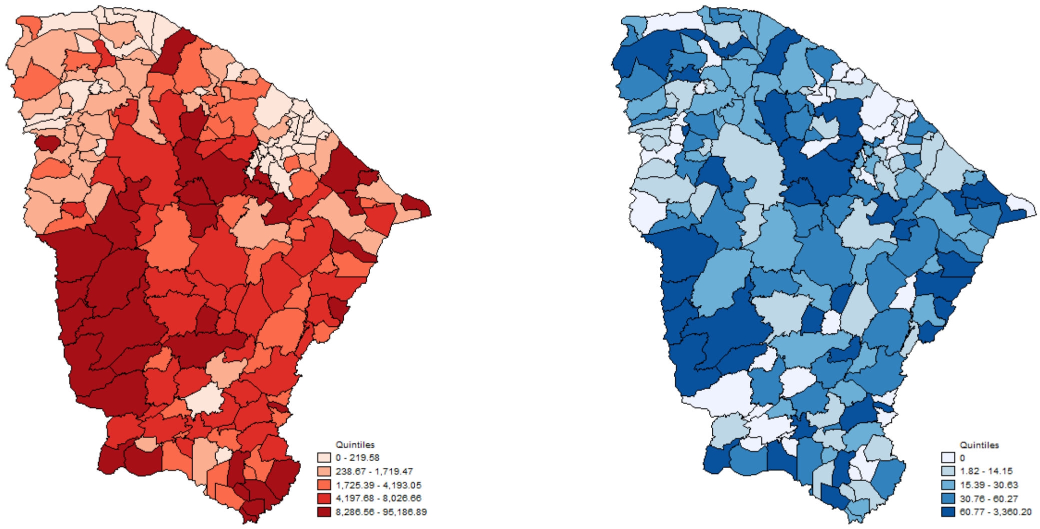


Source: Elaborated by authors.

It is worth noting that municipalities with 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.

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.

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* includes an index of urban infrastructure of municipalities, based on principal components, that includes schools, health establishments, fleet of trucks, and number of firms. All these variables are normalized by 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 includes: 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 reduce the impact of natural disasters on the growth rate of service sector, despite the absence of its mitigating role regarding the agriculture sector. We also include population density as measures of 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. Toya and Skidmore (2007) argue that a large size of government may reflect inefficiency of the public expending, which would lead to large impact of natural disasters. On the other hand, a large size of government may reflect public investment that prevents the impact of natural disasters and helps population to adapt to environmental adversities. Finally, tax revenue as a proportion of total revenue captures the capacity of 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 result in to greater financial resources for the provision of public goods (Yonson et al., 2017).

3.4 Descriptive statistics

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

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

and

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

where AP_{it} is the proportion of population affected 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. Loazya et al. (2012) used 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.[6] De Oliveira (2019) estimate 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 State of Ceará, respectively 12.9 thousand regarding drought and 7.4 due to floods.

[6] Fatalities due to natural disasters has 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 (Centro Universitário de Estudos e Pesquisas em Desastres, 2013), which led us discard it as a measure of the impact of environmental shocks.

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.

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 Km². 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 EMPIRICAL STRATEGY

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

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

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 disaster increases exponentially with hazard. Moreover, Peduzzi et al. (2009) assumes 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 ($\beta_1, \beta_2, \ldots, \beta_k$) on the measure of natural disaster. A semi-elasticity is obtained regarding the impact of hazard (θ) on the measure of the natural disaster. That is,

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

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:

$$\ln ND_{it}^{*} = \alpha + \theta H_{it} + \delta \ln E_{it} + \textstyle\sum_{i=1}^{k} \beta_i \ln V_{k,it-1} + \varepsilon_{it} \tag{4}$$

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).

Nonetheless, a natural disaster is only recorded by the Civil Defence once the mayor of an affected municipality notifies the existence of affected people and/or economic losses due to an environmental shock through a preliminary assessment report (Ministério da Integração Nacional, 2007). It means that the outcome is left-censored, that is

$$\ln ND_{it} = \begin{cases} \ln ND_{it}^{*} \; if \; \ln ND_{it}^{*} > 0 \\ 0, \; otherwise \end{cases}.$$

Moreover, the error term has two components,

$$\varepsilon_{it} = \nu_i + \eta_{it} \tag{5}$$

where $\nu_i \sim NID(0, \sigma_\nu^2)$ is the time-invariant individual random effect and $\eta_{it} \sim NID(0, \sigma_\eta^2)$ is the time-varying idiosyncratic random error, which are assumed to be independent of each other. Thus, the likelihood function is written as

$$L_i = \int_{-\infty}^{\infty} \left\{ \prod_{t=2002}^{2011} \left[\frac{1}{\sigma_\eta} \phi \left(\frac{\ln ND_{it}^* - X_{it}\Gamma - \nu_i}{\sigma_\eta} \right) \right]^{d_{it}} \left[\Phi \left(\frac{-X_{it}\Gamma - \nu_i}{\sigma_\eta} \right) \right]^{1-d_{it}} \right\} f(\nu_i, \sigma_i) d\nu_i \qquad (6)$$

where $X_{it}\Gamma = \theta H_{it} + \delta \ln E_{it} + \sum_{i=1}^{k} \beta_i \ln V_{k,it-1}$. Besides, $\phi(\cdot)$ and $\Phi(\cdot)$ are respectively the probability density function and (pdf) and the cumulative distribution function (cdf) of the standard normal distribution, and $f(\nu_i, \sigma_i)$ is the normal density with mean ν_i and standard deviation σ_i.

It is worth noting that ν_i is modeled as a random effect instead of fixed effect in equation (6). Modeling as fixed effects, it does not impose any correlated restriction between the individual effects and the other explanatory variables, but with nonlinear MLE is generally known to be biased (Heckman, 1981; Hsiao, 1996). Theoretically, the fixed-effects panel Tobit model is affected by the incidental parameters problem (Greene, 2004), i.e., the estimated coefficients are inconsistent unless the number of time periods (T) approaches infinity for each individual i. Honoré (1992) has developed a semiparametric estimator for fixed-effect Tobit models.

The case of random effects model is much more parsimonious in the number of parameters but it requires some restrictive assumptions on the distribution of the individual effects, which are: i) the idiosyncratic error η_{it} is serially uncorrelated; ii) the individual effects ν_i are uncorrelated across individuals; and iii) $\nu_i | X_i \sim NID(\mathbf{0}, \sigma_\nu^2)$, where $X = [\mathrm{H}, \mathrm{E}, \mathrm{V}_1, \ldots \mathrm{V}_K]$ is the vector of explanatory variables. Besides, the marginal effects of an explanatory variable on the expected value of the impact of natural disaster are computed using the Delta method (Greene, 2012).

5 RESULTS

5.1 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 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 deviation of annual precipitation in the 5th quintile of the distribution exhibit, on average, an expected proportion of 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 rainfalls is more likely to generate larger disaster impact to municipalities than the lack of rainfalls.

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 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.

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.

Lagged vulnerability controls are important predictors for the impact of natural disaster 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 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 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 (Hallegate, 2009), which has been the main public policy of drought preparedness in the Ceará state (Gutiérrez et al., 2014).

However, the impact of natural disaster 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 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 in 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 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 Philippines by 0.38%.

Results in Table 2 show that 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 is 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 Philippines normalized by population size. Peduzzi et al. (2009) find elasticities between the number of fatalities and GDP per capita across countries of -0.534 for cyclones,

- 4.535 for droughts, -0.697 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 to additional hypotheses related to the model (4). First of all, it is important to investigate whether the effect of 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 exposed population to droughts have 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 exposed population to these two types of environmental shocks on the expected impact of natural disasters. The test of difference in the coefficients suggest that the effect of exposed population to drought on the expected proportion of affected population is not statistically different from the effect of exposed population to floods. In terms of marginal effects, an increase of 1% in the exposed population to droughts would raise the proportion of 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%.

Nonetheless, the effect of exposed population concerning droughts and floods are 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 larger expected impact in terms of disaster losses than droughts. These findings corroborate the evidence in De Oliveira (2019).

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.

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 (Centro Universitário de Estudos e Pesquisas em Desastres, 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 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).

This evidence is aligned with 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 lead to increasing losses with higher levels of economic development.

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.

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 government (Gutiérrez et al., 2014). As far as these municipalities reach higher levels of development, their vulnerability to natural disasters is reduced due to the increasing in local investment regarding education, urbanization, sanitation, etc. However, larger investment on natural disaster prevention, that depends on federal and state funds (e.g., access to water), may not fully prevent municipalities from the 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.

6 FINAL CONSIDERATIONS

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, exhibit 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 contribute to understand 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).

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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(1^{st} quintile of the distribution of the deviation of annual precipitation); Q2 = I(2^{nd} quintile of the distribution of the deviation of annual precipitation); Q3 = I(3^{rd} quintile of the distribution of the deviation of annual precipitation); Q4 = I(4^{th} quintile of the distribution of the deviation of annual precipitation); Q5 = I(5^{th} 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.