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Not so natural:

unequal effects of public policies on the occurrence of disasters

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Abstract

This paper assesses the effects of public policies on the occurrence of natural disasters related to extreme rainfall. By using a unique and geolocated database on natural disasters in the state of Rio de Janeiro, Brazil, I test whether variables related to public policies - e.g. forest cover and urban infrastructure - affect the occurrence of natural disasters, conditional on the existence of extreme rainfall. Results point to a significant role for public policies in order to mitigate effects of extreme weather events. More specifically, results point to an important role for urban infrastructure, as proper sewage and waste collection, and forest cover in reducing the impacts of extreme rainfall. Moreover, I discuss how these heterogeneous effects have distributional consequences and can be linked to the Environmental Justice literature. Finally, this paper reinforces the idea that adaptation policies to disasters are essential in reducing local vulnerabilities and can yield distributional and fiscal benefits.
Keywords: Natural Disasters, Public Policy, Climate Change, Inequality.
JEL Classification: Q54, Q58.

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Sans quitter votre sujet de Lisbonne, convenez, par exemple, que la nature n'avoit point rassemblé là vingt mille maisons de six à sept étages, et que, si les habitants de cette grande ville eussent été dispersés plus également et plus légèrement logés, le dégât eût été beaucoup moindre et peut-être nul.

Rousseau, 1756

1 Introduction

Climate change and high levels of inequality constitute the main challenges for policymakers in the 21st century.[1] It is safe to say that these challenges, if not treated properly, may lead to disruptive changes, menacing the very form of organization of today's societies, especially Western societies, which are based on representative democracy (Burke et al., 2015; Chancel and Piketty, 2015; Milanovic, 2016).[2] These challenges have not been ignored by economists. Indeed, there is a growing interest that leads to increased economic research on both themes. Moreover, there is also an increasing attempt to reach a broader public with the publication of reports and policy proposals based on recent research.[3]

Climate change is expected to bring an increase in the frequency and intensity of extreme weather events. As a matter of fact, climate change is a complex phenomenon, whose causes are not so obvious to the population. Yet, its most salient feature is the occurrence of more frequent and intense extreme weather events (The Asia Foundation, 2012; Stott et al., 2016).[4] Therefore, the concern with natural disasters and its welfare impacts have become a first order question (Seneviratne et al., 2012; McKibben, 2014).

Although extreme weather events raise the risk of natural disasters, this relationship is not necessarily unequivocal. According to Kahn (2005), rich nations do not suffer less natural disasters than poorer nations. Nevertheless, richer nations have less deaths related to those

[1] The World Economic Forum has recognized these phenomena as global challenges: https://www.weforum.org/agenda/2015/01/inequality-and-climate-change-twin-challenges-of-2015/

[2] Interestingly, Tirole (2017) treats climate change as a major macroeconomic challenge and inserts inequality within the discussion of the moral limits of the market.

[3] See e.g. the World Inequality Report (http://wir2018.wid.world/files/download/wir2018-full-report-english.pdf) on inequality and Gollier and Tirole (2017) on climate change.

[4] For instance, Spence et al. (2011) show that people in England who suffered with floods are more concerned to climate change and consume less energy than the non affected population.

disasters. This might be due to investments in the capacity to deal with those hazards. Investments are also dependent on the political economy equilibrium: Anbarci et al. (2005) discuss how protection to earthquakes depends on the level of income inequality, since more unequal countries are less conducive to collective action.[5]

In this sense, natural disasters cannot be considered exogenous events: there is a set of public policies that can act on the degree of vulnerability of a given region and, thus, help prevent the extension of damages related to natural disasters (World Bank and United Nations , 2010). Indeed, this discussion dates back at least to a controversy between Voltaire and Rousseau.[6] As can be seen on the epigraph above, Rousseau, in a letter to Voltaire, argues that the great 1755 Lisbon earthquake was not only a matter of nature: the design of buildings and urban planning were crucial to the extension of the damages witnessed.

As regards the effects of public policies on natural disasters, Healy and Malhotra (2009) show how expenditures with preparedness for disasters result in less damages. The portfolio of policies that can enhance resilience, however, is not constrained to specific adaptation investments. As Kellenberg and Mobarak (2008) assert, land-use policies are especially important regarding disaster risk. Indeed, land cover is considered a main component in stability analysis related to landslide susceptibility (Van Westen et al., 2008). In addition, urban infrastructure, as represented by proper drainage systems, sewage collection and waste disposal, is also crucial to determine the extension of damages when an extreme rainfall event strikes (Andrew, 2012).

Moreover, natural disasters entail different impacts along the population distribution. There is a growing research on the interplay between inequality and environmental economics that is now being explored empirically. Currie (2011), for instance, explores this link by examining whether the claims of the "Environmental Justice" literature are based on sound empirical evidence. Hsiang et al. (2017) provide a general framework for analyzing the distribution of environmental damages. The latter authors apply this framework to understand the economic effects of deforestation, air pollution and climate. Hallegatte et al. (2015) show how people living in poverty are relatively more vulnerable to shocks caused by natural disasters, such as floods and droughts.[7]

This paper assesses the effects of public policies on the occurrence of natural disasters re-

[5]Besley and Persson (2011) discuss the determinants of the creation of common-interest states.

[6]Voltaire wrote a poem on the relation between that natural catastrophe and God's providence. In a letter answering Voltaire, Rousseau remarked the human responsibility on the disaster (de Almeida Marques, 2005).

[7]Chancel (2017) provides a discussion on different forms of environmental inequalities. On the measurement of environmental inequality, see Boyce et al. (2016).

lated to extreme rainfall. In doing so, it contributes to these two strands of the literature: on the one hand, it provides an evidence of how public policies affect the occurrence of natural disasters related to extreme rainfall. On the other hand, it shows how those effects are heterogeneous among the territory: localities with a bad provision of public infrastructure are the hardest hit.

To investigate the relationship between hydrological disasters and public policies, this article makes use of a unique and geolocated database on natural disasters in the state of Rio de Janeiro, Brazil. Though geographically specific, Rio de Janeiro is considered a global hotspot related to floods and landslides (Dilley, 2005). Therefore, by building knowledge from this particular case, this study can shed light on the discussion of appropriate adaptation policies to increase resilience to climate change and its distributional impacts.

Though there is some evidence on the positive effects of preparedness spending on reducing damages related to natural disasters (Healy and Malhotra, 2009) and a somewhat vast literature in geology on the importance of keeping forests to reduce the risk of landslides and floods (Glade, 2003; Bradshaw et al., 2007; Van Westen et al., 2008), this paper provides evidence based on a detailed geographical scale how the interaction of triggering factors, namely extreme rainfall, with a set of public policy related variables, leads to less natural disasters.

2 Empirical Context

Brazil has had 2,600 deaths and 600,000 unsheltered people due to hydrological disasters, from 2000 to 2015, according to EM-DAT (2010). In relation to monetary damages, CEPED/UFSC (2016) estimates that hydrological disasters caused a loss of BRL 72 billion during the period 1995-2014, or BRL 3.6 billion per year. Regarding the temporal distribution, however, damages are highly concentrated in the more recent years: since 2008, six out of seven years had damages above the mean.[8]

Among Brazilian states, Rio de Janeiro state, due to its geomorphological characteristics (with mountainous and lowland regions) and social vulnerabilities is prone to suffer hydrological disasters as landslides and floods. Despite having an area equivalent to only 0.5% national territory, Rio de Janeiro state has suffered severe monetary damages: during the 1995-2014 period, damages were valued at BRL 10.8 billion, or 15% of total Brazilian losses related to hydrological disasters.

[8]Prices are deflated to 2014 according to the GDP deflator.

In January 2011, the state of Rio de Janeiro, Brazil, suffered the worst natural disaster in country's history.[9] The occurrence of flash floods and landslides due to extreme rainfall led to a disaster with massive consequences. According to World Bank (2012), the disaster has caused the death of more than 900 people and affected a total population of more than 300,000 people. Economic losses amounted to R$ 4,785 million at 2010 prices. This is equivalent to 1% of the state of Rio de Janeiro's GDP. More impressively, this amounts to a loss of 28% of the GDP of the municipalities that were directly affected by the disaster.[10]

Those losses, both in terms of economic as well as welfare, were not evenly distributed between and within municipalities. Regarding disparity between municipalities,[11] the city of Nova Friburgo has concentrated 60% of the total affected population. Within municipality impacts were unevenly distributed as well: the parcel of population that has got unsheltered has varied from 3.1% to 21.9% in the municipalities that suffered with the flash floods and landslides (World Bank, 2012). In addition, the lion's share of those who suffered home losses were the poor who live in risky areas without a proper provision of public goods (Freitas et al., 2012).

From looking to this episode, one question arises almost immediately: why are the effects of extreme weather events so heterogeneous? This is a first-order question that links to two mounting problems: climate change and economic inequality. More specifically, it is important to better understand the distributional consequences of environmental degradation (Hsiang et al., 2017)

3 Data description and Summary Statistics

3.1 Dataset construction of geolocated natural disasters

The Brazilian institutional framework related to natural disasters begins in 1969 with a Presidential Decree (DL 950/1969) that created the Special Fund for Public Calamities. In 1988, a new Decree (97274/1988) created the National System of Civil Defense. As of 2012, a new act (Act 12608/2012) established the current institutional framework and creates the

[9] One day after the disaster has occurred, local media had already classified it as the worst climate-related tragedy in the country: http://g1.globo.com/rio-de-janeiro/chuvas-no-rj/noticia/2011/01/chuva-na-regiao-serrana-e-maior-tragedia-climatica-da-historia-do-pais.html

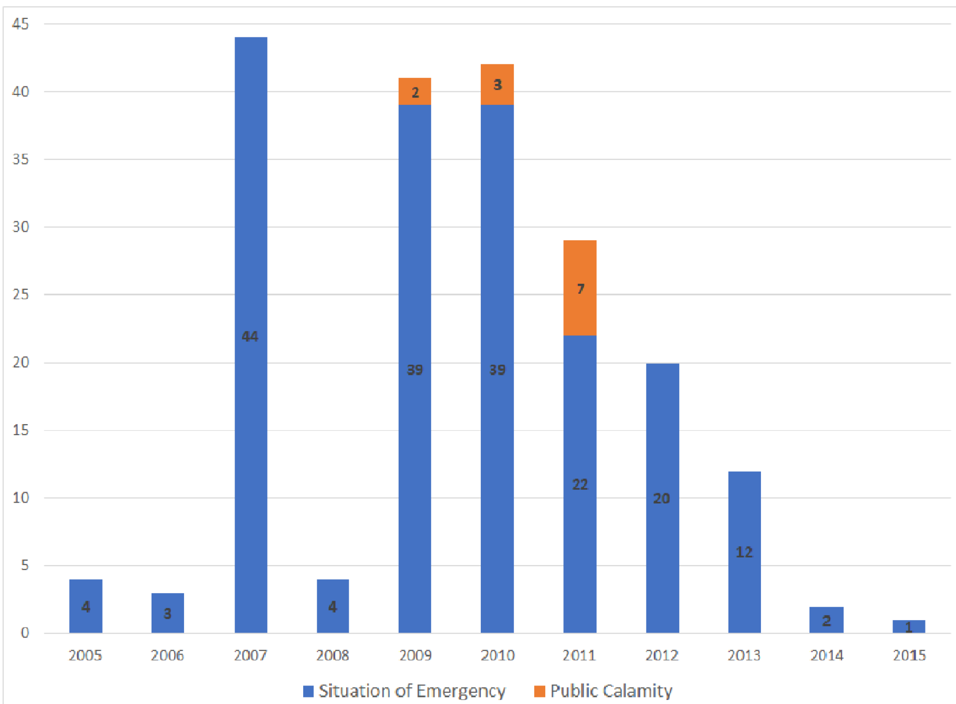
[10] World Bank (2012) provides a list of these municipalities as well as a report of total losses and damages related to this megadisaster.

[11] The tragedy has affected seven municipalities at the Serrana Region of the state.

National System of Protection and Civil Defense.[12] This new act has brought the idea of risk management and thus tries to improve actions of prevention.

Under this framework, when a natural hazard occurs, municipalities may claim for the recognition of two states: situation of emergency and public calamity. These states diverge in intensity, but they represent a situation where the municipality has suffered severe damages. Specifically, these damages encompass at least two spheres of: human, material, environmental and economic losses. Respectively, it means at least one death or 99 affected humans; at least one public or private building destroyed; water, air or soil contamination that leads to a supply disruption to at least 10% of population; and economic losses equivalent to 8.33% of the current net income from the municipality. The Figure 1 below shows the distribution of disasters by year and classification at Rio de Janeiro, from 2005 to 2015.

Figure 1: Hydrological disasters at Rio de Janeiro: 2005-2015



Source: Ministry of National Integration and IBGE

As seen on Figure 1, there was a concentration of disasters in the period 2007-2011, which was more rainy than average. The triennial 2009-2011 hit especially hard Rio de Janeiro, with 12 declarations of public calamity.

The federal recognition of a disaster grants access to transfers from the federal government

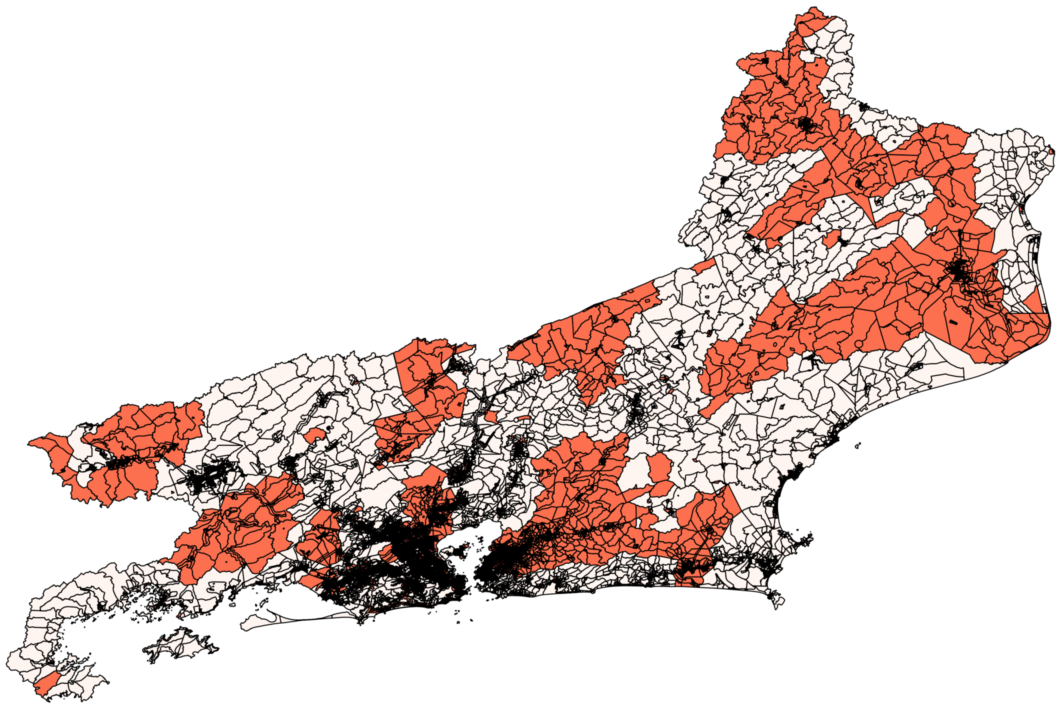
[12] Ganem (2014) provides a full description of the evolution of this institutional framework.

to response and reconstruction, but also improves access to prevention. In order to be able to apply for these funds, municipalities must fill a detailed form with information of the disasters. These forms include the localization of the disaster in a given municipality. The Ministry of National Integration keeps a database - Sistema Integrado de Informações sobre Desastres (http://s2id.mi.gov.br/) - with all the official documents related to the pledge of recognition of emergency situation or public calamity that municipalities send to the federal government.[13] These documents contain a rich set of information including: the type of disaster and its causes, damaged area, number of deaths, economic sectors and number of people affected and value of the damages. Regarding the information utilized in this paper - the localization of occurrence of a hydrological disaster -, documents are very detailed - sometimes they go on the level of the street that has suffered with the disaster. More often, however, the level is on the neighborhood that has been affected.

Therefore, by using the information contained on these documents, I have geolocated floods and landslides that occurred in the state of Rio de Janeiro between 2005 and 2015. Thus, disasters, in its crude form, are composed by a shapefile of points and polygons located at Rio de Janeiro state. Moreover, the Brazilian Institute of Geography and Statistics (IBGE) provides shapefiles at the census tract level, the least geographical unit utilized for the Census accounting. Hence, by merging the two shapefiles, it is possible to build a database of natural disasters at the census tract level. This is a necessary step since the variables on infrastructure are defined at the census tract level. Therefore, the main dependent variable - $Disaster_{it}$ - is a dummy that indicates whether a census tract i was affected by a disaster at year t. Figure 2 provides a map of Rio ed Janeiro, by census tracts, showing the localities affected by a disaster in the analyzed period.

[13] Until 2012, these documents were more detailed and were called Damage Assessment Form (Formulário de Avaliação de Danos, in portuguese). After 2012, under the new act, these documents became simpler and are, since then, called Disaster Information Form (Formulário de Informação do Desastre).

Figure 2: Hydrological disasters by census tract between 2005 and 2015



Source: Ministry of National Integration and IBGE

As disaster evaluation is done during the disaster occurrence, it is possible that total impacts are underestimated. In order to overcome this problem, I utilize only a variable of occurrence which is more feasible to be accurately measured at the initial level. A possible way to overcome this problem would be using satellite images, as in Guiteras et al. (2015). This would be a promising way of future research on damages extension. A possible assessment of severe damages is the death rate related to disasters. The Brazilian Ministry of Health keeps a database with deaths caused by external causes, by municipality. We summed up the deaths related do hydrological disasters and created the variable:

$$Death\ Rate_{it} = \frac{Deaths_{mt}}{Population_{mt}} * Population_{i2010}\ if Disaster_{it} = 1$$

Where $Deaths_{mt}$ are deaths by municipality m at year t, $Population_{mt}$ is the total population of municipality m, at year t and $Population_{i2010}$ is the population of census tract i at 2010, year of the last demographic census.

3.2 Independent Variables

3.2.1 Extreme Rainfall as a Trigger

As described extensively by the literature, the occurrence of extreme rainfalls in a short lapse of time is a crucial trigger for floods and landslides to happen (Van Westen et al., 2008). Therefore, in order to account for the occurrence of extreme precipitation within a year, I reckon the number of days with precipitation levels above 100 millimeters in 24 hours and weight each day by its difference to the threshold of 100 mm/day. The level of precipitation of 100mm/day is considered to increase the risk of landslides and floods that cause significant damages (Paulais, 2012).

The information on precipitation has been collected from 137 gauge stations located at Rio de Janeiro. This information comes from three different sources: the National Institute of Meteorology (INMET), the Institute of Meteorology of the city of Rio de Janeiro (Alerta Rio) and the National Water Agency (ANA).[14] Both have reliable daily data on precipitation. After collecting data and counting the number of days with rain above 100 mm/day for each year, I have used the software *QGis* to interpolate, through the inverse distance weighting method, data in order to have figures for the whole sample of census tracts. Hence, the variable $Extreme\ Rainfall_{it}$ that reflects the weighted number of days with rainfall above 100mm/day for each census tract i and year t has been created.

Other variables of rainfall are utilized as robustness checks to the main extreme rainfall chosen in this paper. Thus, in addition to $Extreme\ Rainfall_{it}$, we provide tests with the following variables: $Count\ 100mm_{it}$, $Count\ 30mm_{it}$, $Precipitation\ p99_{it}$ $MaxRainfall_{it}$ and $Cum7days_{it}$. Respectively, these variables measure the number of days in a given year with rainfall above 100mm and 30mm, the number of days with rainfall above the percentile 99th based on daily distribution between years 2005 and 2015, the maximum daily rainfall at year t and the maximum cumulative rainfall in 7 days in a given year t .[15]

[14] The Brazilian Center for Natural Disaster Monitoring and Alert - CEMADEN - also has gauge stations that measure precipitation. However, data is available only from 2013. Thus, introducing these data would lead to a problem of unbalancing the sample of interpolated data (Hsiang, 2016)

[15] An additional variable could be the rainfall thresholds calculated monthly by the Rio de Janeiro's department of mineral resources (DRM-RJ). However, two caveats prevent the utilization of this variable: (i) DRM-RJ only provides this information from January 2012; (ii) DRM-RJ focuses specifically on landslides and does not provide information related to floods.

3.2.2 Forest Cover and Infrastructure

The literature on floods and landslides susceptibility discusses how the maintenance of forest cover reduces the risk of a given terrain (Gentry and Lopez-Parodi, 1980; Dapples et al., 2002; Kamp et al., 2008; Vasantha Kumar and Bhagavanulu, 2008; Pradhan and Lee, 2010; Liao et al., 2012). Indeed, NASA's Global Landslide Model considers the steepness of the terrain, the amount of deforested area, the existence of roads, the lithology and the proximity to tectonic faults as main factors that drive the susceptibility of the terrain.[16] Considering the importance attributed to forest cover, I use the variable $\textit{Forest Cover}_{it}$, which is calculated by summing up the share of census tract area that was covered by forest at year t. In order to reckon this variable, I utilize raster data on land-use provided by MapBiomas (http://mapbiomas.org/).

As regards the provision of public infrastructure, de Goyet et al. (2006) argues that disaster risk management policies must reduce the vulnerability of a locality. As a result, the building of resilient infrastructure is crucial to reduce vulnerabilities related do extreme weather events (Andrew, 2012). In order to account for the effects of public infrastructure, I considered three distinct dimensions that might affect resilience: the share of households per census tract that make use of open sewage ditches; the share of households that dispose waste at illegal dumps and the share of households that are served by streets with drainage system. These information are all available at the website of the Brazilian Institute of Geography and Statistics and are related to the Census of 2010.

3.3 Summary Statistics

Table 1 summarizes the data utilized in this paper. Besides the variables discussed above, it includes the share households in a given census tract that are not in paved streets and a dummy indicating whether the census tract is a slum. Considering the full sample utilized in the main part of the paper, 6.12% of the census tracts at Rio de Janeiro have been hit by floods or landslides. The state of Rio de Janeiro has important figures regarding the vulnerability of its population: 6.3% of its households dump sewage in open ditches, as well as 1% use illegal waste dumps. 42% of the households do not have drainage system in its streets, which are not paved by 27.6%. As regards forest cover, the average area covered is 2.9% of the census tracts. Finally, the measure of extreme rainfall has on average 1.1 weighted day by year of rainfall above 100mm/day. However, there is a high variability,

[16]See on: https://pmm.nasa.gov/applications/global-landslide-model

ranging from 0 to 28 weighted days.

Table 1: Summary Statistics

VARIABLES	(1) mean	(2) St. dev.	(3) minimum	(4) maximum	(5) number of observations
Disaster	0.0612	0.240	0	1	311,498
Extreme Rainfall	1.081	1.603	0	28.30	311,487
Open Sewage	0.0629	0.176	0	1	290,378
Illegal Waste Dump	0.00911	0.0524	0	1	286,935
No Drainage System	0.420	0.411	0	1	290,378
Forest Cover	0.0288	0.113	0	1	311,498
Streets not paved	0.276	0.390	0	1	290,378
(Dummy of) Slum	0.117	0.321	0	1	311,498

Note: sample include the period 2005-2015. Observations comprise census tracts that cover the whole state of Rio de Janeiro.

Table 2 provides results based on *t* test on the equality of means of the variables in census tracts affect and not affected by disasters. Overall, the differences are significant, which indicates a difference in the odds of occurring disasters based on the variables used in this paper. The number of weighted days with extreme precipitation are much higher (more than 3 times) in census tracts with disasters than otherwise.

Regarding the provision of public goods, as one might expect, census tracts with disasters have, on average higher levels of open sewage, wastelands, inadequate drainage systems and less forest cover and health establishments. Regarding the share of households that are located in unpaved streets and the share of slums, the results go in the opposite direction: disasters happen more in places with paved streets and outside slums, at least in this specific research context. Overall, these statistics reinforce the view that the occurrence of floods and landslides are also dependent on the local infrastructure and land use, as discussed before.

Table 2: Sample statistics - difference between census tracts with and without disasters

	No Disaster		*Disaster*		
	(1)	(2)	(3)	(4)	(5)
VARIABLES	mean	sd	mean	sd	diff
Extreme Rainfall	0.938	1.318	3.276	3.195	-2.339***
Open Sewage	0.0624	0.175	0.0706	0.182	-0.008***
Illegal Waste Dump	0.00892	0.0518	0.0120	0.0608	-0.003***
No Drainage System	0.420	0.412	0.431	0.398	-0.011***
Forest Cover	0.0296	0.115	0.0161	0.0819	0.0135***
Streets not paved	0.278	0.391	0.251	0.369	0.027***
(Dummy of) Slum	0.118	0.323	0.0907	0.287	0.028***

Note: sample include the period 2005-2015. Columns (1) and (2) provide descriptive statistics the census tracts that did not suffer any disaster in the whole period and columns (3) and (4) provides descriptive statistics for the census tracts that did suffer at least one natural disaster in the period analyzed. Column (5) provides the difference between the means. Observations comprise census tracts that cover the whole state of Rio de Janeiro. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

3.4 Empirical framework

This subsection details the empirical strategy of this paper. In order to analyze the effects of different types of public policies on the occurrence of disasters, I run a fixed-effects model on a panel of 28,317 sectors covering the period from 2005 to 2015 This gives rise to 311,487 observations.

Identification strategy relies on two main factors that differ from extant literature on the effects of policies on disasters. First, this paper matches geolocated data on natural disasters and extreme rainfall. This allows me to implement a strategy that reduces measurement error and potential confounding factors.[17] Second, as argued by Dell et al. (2014), there is a growing body of the literature that uses weather shocks to exactly identify outcomes. Moreover, mostly of the literature does not account for the interaction with triggering factors (Kahn, 2005; Kellenberg and Mobarak, 2008; Neumayer et al., 2014). In this paper, I consider the heterogeneous effects of distinct variables that are somehow related to policy decisions.

An additional point must be considered in the empirical strategy: spatial dependence. As argued by Hsiang (2016), it is important to account for spatial and temporal dependence in climatic exposure. In order to account for this potential bias, I make use of two different strategies: (i) robust standard errors are clustered at the gauge station level, since the inter-

[17] Fuchs (2014) uses a similar strategy regarding the effects of droughts in elections.

polation necessarily leads to spatial dependence; and (ii) I apply "Conley" spatial standard errors (Conley, 1999). As Harari and La Ferrara (2013) point, when there is clearly spatial dependence, it is preferable to conduct estimation by OLS, rather than logit or probit estimators. The authors, in addition, argue that logit and probit estimators may lead to biased estimators when the dependent variable is a dummy of 'rare events'. Therefore, benchmark specification is defined by equation (1):

$$Y_{it} = \beta_1 * Extreme\ Rainfall_{it} + \beta_2 * Extreme\ Rainfall_{it} * X_i + \beta_3 * X_{it} + \lambda_i + \mu_t + \varepsilon_{it} (1)$$

Where Y_{it} is a dummy that indicates whether there was a natural disaster at census tract i, year t; $Extreme\ Rainfall_{it}$ assigns the weighted number of days in a given year with rainfall above 100mm/day; X_{it} is a vector with variables related to different public policies: $Forest\ Cover_{it}$, $Open\ Sewage_i$, $Illegal\ Waste\ Dump_i$, $No\ Drainage_i$; λ_i and μ_t are specific census tract and time fixed effects, as well as ε_{it} is the error term.

4 Results

Empirical results are presented in Tables 3-7. Table 3 presents results of different variables related to rainfall.

Table 3: Extreme rainfall and natural disasters

	(1)	(2)	(3)	(4)	(5)	(6)
Extreme Rain	0.029***					
	(0.007)					
Count 100mm		0.030***				
		(0.011)				
Count 30mm			0.003**			
			(0.001)			
Precipitation p99				0.011**		
				(0.005)		
Max Rainfall					0.001***	
					(0.000)	
Cum 7 days						0.002***
						(0.001)
Observations	311,487	311,487	311,487	311,487	311,487	311,487
R-squared	0.228	0.216	0.211	0.212	0.222	0.227
Number of census tracts	28,317	28,317	28,317	28,317	28,317	28,317
Census Tracts Fixed Effects	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Number of clusters	135	135	135	135	135	135

Notes: Analysis is based on a sector-by-year panel data set covering the period 2005-2015. Sample includes 28.317 census tracts. Dependent variable is a dummy that indicates whether there was a hydrologic disaster at the census tract. All regressions include period and specific local fixed effects. Robust standard errors are clustered at the gauge station level. Significance: *** p<0.01, ** p<0.05, * p<0.1.

All results from Table 3 are based on fixed-effects estimations. Therefore, these results, conditioned on fixed effects by sector, present a positive and statistically robust relationship between rainfall, measured in different ways, and hydrological disasters. Results from columns (1) and (2), for instance, imply that an extra day of rainfall above 100mm in a year increases the probability of a disaster by 3 percentage points.

Results described above show the importance of rainfall to disasters by using a detailed geographical dataset. It is important, as well, to try to devise the extent of the damages cause by extreme rainfall. Table 4 presents estimates of the effects of precipitation on the measure of deaths rate by sector.

Table 4: Death related to hydrological disasters and extreme rainfall

	(1)	(2)	(3)	(4)	(5)	(6)
Extreme Rain	1.389					
	(1.671)					
Count 100mm		2.797				
		(1.829)				
Count 30mm			0.985*			
			(0.525)			
Precipitation p99				1.547		
				(1.296)		
Max Rainfall					0.226	
					(0.138)	
Cum 7 days						0.136
						(0.086)
Observations	310,723	310,723	310,723	310,723	310,723	310,723
R-squared	0.003	0.003	0.004	0.003	0.004	0.003
Number of census tracts	28,317	28,317	28,317	28,317	28,317	28,317
Census Tracts Fixed Effects	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Number of clusters	135	135	135	135	135	135

Notes: Analysis is based on a sector-by-year panel data set covering the period 2005-2015. Sample includes 28.317 census tracts. Dependent variable is a dummy that indicates whether there was a hydrologic disaster at the census tract. All regressions include period and specific local fixed effects. Robust standard errors are clustered at the gauge station level. Significance: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Although point estimates are not so precise - the variable of death rate by sector was created from municipal-level data - results point to a positive effect of rainfall on the death rate due to natural disasters.

4.1 Heterogeneous Effects

As discussed before, the effects of extreme weather events are not evenly spread among census tracts. Therefore, more important than establishing a relationship between rainfall and disasters, it is to understand the heterogeneous effects of rainfall in causing disasters. In order to account for this heterogeneity, we regress the variable $Disaster_{it}$ on the interaction of rainfall with some variables related to public policies. Table 5 provides results for the effects of land-use variables on natural disasters.

Table 5: Land-use, extreme rainfall and natural disasters

VARIABLES	(1) Disaster	(2) Disaster	(3) Disaster	(4) Disaster	(5) Disaster
Extreme Rain	0.031***	0.030***	0.032***	0.031***	0.031***
	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)
Forest	0.063		0.064	0.055	0.054
	(0.051)		(0.051)	(0.052)	(0.054)
Extreme Rain x Forest	-0.034***		-0.034***	-0.032***	-0.032***
	(0.012)		(0.012)	(0.012)	(0.012)
Extreme Rain x Slum		-0.006	-0.006	-0.006	-0.006
		(0.009)	(0.009)	(0.009)	(0.009)
Observations	311,289	311,487	311,289	293,238	293,131
R-squared	0.229	0.229	0.229	0.237	0.237
Number of census tract	28,299	28,317	28,299	26,658	26,652
Census Tracts Fixed Effects	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y
Sample	All	All	All	Urban	Urban and
Sample					Forest<1
Number of clusters	135	135	135	131	131

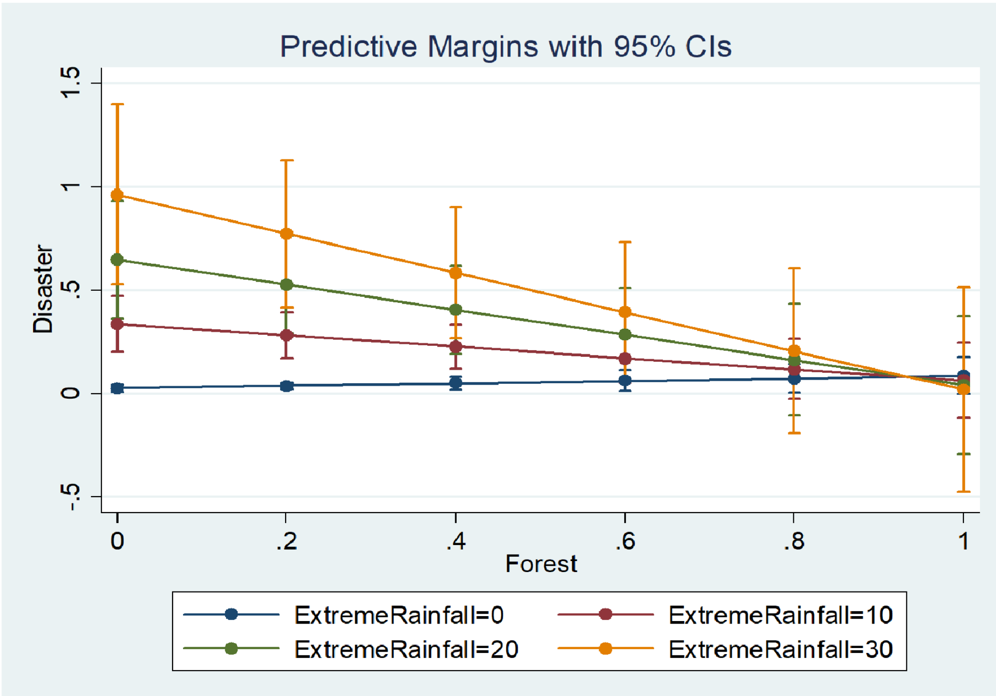
Notes: Analysis is based on a sector-by-year panel data set covering the period 2005-2015. Sample includes 28.317 census tracts. Dependent variable is a dummy that indicates whether there was a hydrologic disaster at the census tract. All regressions include period and specific local fixed effects. Robust standard errors are clustered at the gauge station level. Significance: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

From column (1), it can be seen that forests provide a protection when an extreme rainfall occurs: census tracts with more forest cover suffer significantly less floods and landslides. Figure 3 shows the margin plots of the interaction based on results from Column (1). However, this result might be related to the fact that more forest cover is present in less populated places. Though, this problem is accounted for by introducing census-tract fixed effects, which control for any unobservable characteristic of the census tracts holding fixed in time, results from Columns (4) and (5) only consider, respectively, urban census tracts and

Furthermore, Rio de Janeiro has a significant share of its population living in slums - 13.8%. Thus, land-use policies related to the urban occupation are especially important at Rio de Janeiro. Results from column (2) allow for the interaction of rainfall and the existence of a slum at the census tracts: there is no statistical difference between the census tract being a slum or not. This might be due to the fact that it is not important *per se* if a household is in a slum, but how it is the public provision of infrastructure. On columns (3), (4) and

(5), results consider both the interactions of slums and forest cover and do not show any qualitative changes.

Figure 3: Margin Plots of Column (1) of Table 5



Source: own elaboration

Table 6 displays results related to the effects of public infrastructure provision on the occurrence of natural disasters.

Table 6: Public provision of infrastructure, extreme rainfall and natural disasters

VARIABLES	(1) FE	(2) FE	(3) FE	(4) FE	(5) FE	(6) FE
Extreme Rainfall	0.029***	0.027***	0.028***	0.023***	0.026***	0.022***
	(0.007)	(0.007)	(0.007)	(0.008)	(0.008)	(0.007)
Extreme Rainfall X Open Sewage		0.048**				0.039**
		(0.021)				(0.017)
Extreme Rainfall X Illegal Waste Dump			0.162***			0.133***
			(0.023)			(0.020)
Extreme Rainfall X No Drainage				0.021*		0.030*
				(0.011)		(0.015)
Extreme Rainfall X No Paving					0.013	-0.018
					(0.010)	(0.012)
Observations	286,924	286,924	286,924	286,924	286,924	286,924
R-squared	0.237	0.240	0.240	0.241	0.238	0.245
Number of census tract	26,084	26,084	26,084	26,084	26,084	26,084
Census tract FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Dependent Variable Mean	Y	Y	Y	Y	Y	Y
Number of clusters	132	132	132	132	132	132

Notes: Analysis is based on a sector-by-year panel data set covering the period 2005-2015. Sample includes 26,084 census tracts. Dependent variable is a dummy that indicates whether there was a hydrologic disaster at the census tract. All regressions include period and specific local fixed effects. Robust standard errors are clustered at the gauge station level. Significance: *** p<0.01, ** p<0.05, * p<0.1.

Before analyzing the interaction of extreme rainfall with public policies' variables, it is worth noting that the coefficient of *Extreme Rainfall* is, again, positive and significant among all the specifications. An additional day of extreme rainfall implies an increase between 2 and 3 percentage points in the probability of occurring a natural disaster in any specific locality in the state of Rio de Janeiro.

Regarding the effects of the variables related to public policies, columns (2)-(5) present, respectively, the effects of open sewage, illegal waste dump, absence of drainage systems and absence of paved streets on the chances of occurring a natural disaster, when interacting with the extreme rainfall variable. Column (6) presents results with all the variables added to the estimated model. Overall, a remarkable feature of Table 6 is that estimates are in accordance with expected: public provision of infrastructure matters for resilience. From columns (2) and (6), it can be seen that census tracts with sewage problems are more prone to suffer floods and landslides for a given amount of extreme rainfall. The same happens with localities that have illegal waste dump: results from columns (3) and (6) show a very robust and positive relationship between the interaction of inadequate waste disposal and extreme precipitation and natural disasters. As regards drainage systems, columns (4) and

(6) also confirm the hypothesis that infrastructure matters. Interestingly, the absence of paved streets in a given locality does not seem to affect the probability of occurrence of a natural disaster. This result shows that there are some specific assets that are important to enhance local resilience (Hallegatte et al., 2016).

As argued before, an alternative to account for spatial dependence is by applying "Conley" spatial standard errors (Conley, 1999; Hsiang, 2016). Table 7 presents results correcting for spatial dependence applying Conley (1999).

Table 7: Effects of public policies on disasters: different spatial dependence strategies

VARIABLES	(1) FE with cluster	(2) Buffer 5 KM	(3) Buffer 10 KM	(4) Buffer 20 KM
Extreme Rainfall	0.023***	0.023***	0.023***	0.023***
	(0.008)	(0.007)	(0.008)	(0.009)
Extreme Rainfall X Open Sewage	0.038**	0.038***	0.038***	0.038**
	(0.017)	(0.009)	(0.012)	(0.016)
Extreme Rainfall X Wasteland	0.127***	0.127***	0.127***	0.127***
	(0.020)	(0.021)	(0.023)	(0.018)
Extreme Rainfall X No Drainage	0.017	0.017**	0.017*	0.017*
	(0.010)	(0.007)	(0.009)	(0.010)
Extreme Rainfall X Forest	-0.051***	-0.051***	-0.051***	-0.051**
	(0.018)	(0.014)	(0.017)	(0.021)
Observations	286,924	286,924	286,924	286,924
Number of Census Tracts	26,084	26,084	26,084	26,084
Census tract FE	Y	Y	Y	Y
Time FE	Y	Y	Y	Y

Notes: Analysis is based on a census tract-by-year panel data set covering the period 2005-2015. Sample includes 26,084 census tracts. Dependent variable is a dummy that indicates whether there was a hydrologic disaster at the census tract. All regressions include period and specific local fixed effects. Robust Standard errors in parenthesis corrected for spatial dependence, by clustering in column (1) and Conley correction in columns (2)-(4) following Hsiang (2010). Cutoffs are, respectively, of 5km, 10km, 1km and 20km. Significance: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

All results from Table 7 consider extreme rainfall and its interaction with the variables that show significance in Tables 5 and 6. Column (1) provides results based on robust standard errors clustered at the gauge level, whereas Columns (2)-(4) provide results with Conley standard errors, with distance cutoffs ranging between 5 and 20 kilometers. Results are very much alike with the ones shown before: where public infrastructure lacks, disasters occur with more frequency. Regarding forest cover, its protective feature remains with the specifications above. Even considering a buffer of 20 kilometers to account for spatial dependence, results remain robust. The main difference regards the effects of absence of drainage systems that are not significant when clustered at the gauge level.

5 Discussion

The results above point to very clear conclusions. First, localities can have their vulnerabilities to hydrological disasters significantly reduced. Indeed, as highlighted by Healy and Malhotra (2009), expenditures with preparedness lead to reduced damages related to natural disasters. The authors reckon, in the U.S. context, that a 1 Dollar invested in preparedness generates a reduction in future damages whose Net Present Value (NPV) is 15 Dollars. Results in this paper show a remarkable role for urban infrastructure in reducing the occurrence of disasters. As shown on Table 6, the effects of appropriate sewage and waste collection are non negligible: the effects of reducing open sewage and illegal waste disposal from 100% to zero would mean a reduction in the probability of occurrence of disaster (given one day of extreme rainfall at 100mm/day) of 6.1 and 15.5 percentage points, respectively.

Another set of policies that reduces vulnerability to natural hazards relates to the maintenance of forest cover. It is well established that deforested areas are more prone to floods and landslides, as reduced forest cover leads to an increase in erosive processes and less water retention (Gentry and Lopez-Parodi, 1980; Dapples et al., 2002). Indeed, China's Sloping Land Conversion Program, which aimed to convert almost 15 million hectares from cropland to forests was motivated by the devastating floods along the Yangtze River (Liu and Diamond, 2005; Bennett, 2008). In this paper, I also provide evidence for the importance of forest cover as a buffer of resilience against natural hazards. As seen on Figure 3, census tracts with more forest cover are less vulnerable to extreme rainfall: basically, a census tract with 80% of forest cover is fully insured against extreme weather events. These effects are valid even when one considers urban census tracts with forest cover that do not represent their total area (see Table 5, column (5)).

Moreover, it is worth noting that natural disasters do not strike people or localities in the same extension: effects are heterogeneous and, particularly, unequal. Hallegatte et al. (2015) provide evidence that natural disasters hit hardest the poor. This paper provides evidence that goes along the previous literature. However, interestingly, it is not census tract located at usually poorer places, as slums, that are more affected by extreme rainfall. The important features are those related directly to infrastructure. In particular, census tracts with inappropriate access to sewage, drainage and waste disposal are those more vulnerable to natural disasters. This feature provides an important link with the literature on Environmental Justice. Walker and Burningham (2011), for instance, show that the exposure to flood risk in the United Kingdom is highly unequal.[18]

[18] The two most deprived deciles are 3 to 4 times more exposed to flood risk than the least deprived decile (Walker and Burningham, 2011).

Finally, though it is not a theme of this article, it is worth mentioning that damages related to natural disasters can be very severe to municipalities economic and fiscal capacities. Young et al. (2014) estimate that the state of Rio de Janeiro has suffered losses that amount to 1.3% of its GDP between 2001 and 2010, due to hydrological disasters. However, the municipalities affected by the massive disaster of 2011 have suffered a loss of 28% of their GDP. This situation, combined with the lack of investments in prevention,[19] can only lead to a situation of more vulnerability to climate change. Indeed, Unterberger (2017) discuss how flood damages decrease municipalities' fiscal capacity, by reducing their current income and annual result. Therefore, it is crucial to develop cost-effective policies to reduce disaster losses (Hallegatte, 2012), since they can be welfare as well as fiscal enhancing.

6 Conclusion

There is a recognition that the damages and occurrence of natural disasters are affected by public policies (World Bank and United Nations , 2010; Hallegatte et al., 2016). Though there is some evidence on the positive effects of preparedness spending on reducing damages related to natural disasters (Healy and Malhotra, 2009) and a somewhat vast literature in geology on the importance of keeping forests to reduce the risk of landslides and floods (Glade, 2003; Bradshaw et al., 2007; Van Westen et al., 2008), this paper provides evidence based on a detailed geographical scale how the interaction of triggering factors, namely extreme rainfall, with a set of public policy related variables, leads to less natural disasters. More specifically, the stock of urban infrastructure and forest cover appear to have important effects on reducing the occurrence of natural disasters. These results provide useful insights in order to enhance resilience of localities more prone to landslides and floods and, in turn, reduce the vulnerability of their living populations.

Moreover, natural disasters have distributional effects. In general, people living in poverty are relatively more vulnerable to shocks caused by natural disaster. This paper provides evidence in this sense, by showing how census tracts with inappropriate infrastructure suffer more with extreme weather events. In this sense, extreme weather events have unequal effects due to different levels of public infrastructure.

Given the increasing importance of natural disasters in a context of climate change, the understanding of extreme weather events and its effects are of first order importance. By looking at a detailed geoscale that allows to better understand the heterogeneous effects of

[19] Young et al. (2014) show that on average only 62% of the budget allocated to geotechnical stabilization was executed at the municipality of Rio de Janeiro between 2008 and 2013.

hydrological events, this paper can help in providing an appropriate framework to discuss adaption policies to climate change, especially in developing countries.

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