An analysis of the determinants of flood damages

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Abstract

In this paper we analyze mortality caused by 2,194 large flood events between 1985 and 2008 in 108 countries. Unlike previous studies that looked at natural-disaster mortality, we find that year-to-year changes in income and institutional determinants of vulnerability do not affect flood mortality directly. Income and institutions influence mortality only indirectly, through their impact on the intensity and frequency of floods. Population exposure affects the number of deaths both directly and indirectly. Higher population exposure results in more deaths once the flood has occurred, but it is associated with smaller floods. In developing countries it also reduces the count of floods.

1. Introduction

Destructive natural events occur regularly across the world, although most do not cause enough damage to be considered natural disasters. Among those that do, floods are the most common. Table 1 shows that between 1985 and 2009, floods accounted for 40 percent of the natural disasters (another 31 percent were storms).[1] Combined, floods and storms represented 44 percent of the deaths, 67 percent of the number of people affected and the bulk of economic damages caused by natural disasters.

Figure 1 shows that of all the natural disasters over the last 25 years, floods and storms are becoming more frequent. While part of the observed increase may reflect improved reporting, other types of disasters do not exhibit the same trend. The growth in hydrological

[1] To be included in the EM-DAT global disaster database, an event needs to fulfill at least one of the following criteria: (i) 10 or more people killed, (ii) 100 or more people reported affected (typically displaced); (iii) a declaration of a state of emergency; (iv) a call for international assistance. Apart from floods and storms, other natural disasters accounted for in the database are earthquakes, extreme temperatures, droughts, wildfires, wet and dry mass movements (landslides, avalanches, etc.), and volcanoes (OFDA/CRED 2010).

disasters is believed to have two causes. The first is increased populations in flood plains and other high-risk areas (Freeman et al. 2003; IPCC 2007a, Chapter 3), and the second is an increase in the frequency and intensity of extreme weather events. This second development is associated with climate change and is expected to become more pronounced over this century. A warmer climate, with its increased climate variability, will increase the risk of both floods and droughts (Wetherald and Manabe 2002; IPCC 2007a, Table SPM2). Scientists also report an increase in hurricane intensity over the last 30 years (Emanuel 2005; IPCC 2007b), and IPCC (2001) and Swiss Re (2006) report dramatic increases in related damages over time.

There is general agreement that the impacts of climate change will be larger in poorer countries (Tol 2008). This is because poorer countries have a greater exposure to climate change, particularly in agriculture and water resources and have a lower adaptive capacity (Adger 2006; Smit and Wandel 2006; Tol and Yohe 2007). Regarding the immediate impacts of flood events, according to data from the Dartmouth Flood Observatory (DFO 2010) for large flood events, during the last 25 years, in a given year, over 95 percent of the deaths caused by floods were recorded in developing countries. This number was higher than the percentage of flood events and population concentrating in the same countries (approx. 77 and 84 percent, respectively).

Recent studies have analyzed the role of socioeconomic and institutional factors in determining the mortality of earthquakes (Anbarci et al. 2005, Escaleras et al. 2007) and of all disaster types (Kahn 2005). A common finding is that richer nations and democracies suffer fewer deaths from natural disasters and that corruption and inequality increase mortality. The intuition is that richer, less corrupt, and more egalitarian countries are better able to agree on, invest in and enforce zoning and building codes and other preventive measures. In addition, Keefer et al. (2010) find that higher earthquake propensity results in increased earthquake mortality prevention and fewer deaths.

In this paper we analyze mortality caused by floods using new data on 2,194 large flood events in 108 countries between 1985 and 2008. We model the immediate effects of floods as a function of their physical intensity and the vulnerability of the population and infrastructure affected. The physical intensity of a flood is measured by the extent of the area affected, the duration of the event and its severity in terms of the length of the recurrence interval. The vulnerability of the affected area depends on the number of people exposed to the flood and the level of preparedness and mitigation activities, which in turn are assumed to be a function of socioeconomic factors such as income, and the ability of the government to effectively provide public services.

Focusing on floods is interesting for at least two reasons. First, floods are increasingly relevant in the context of climate change and its distributional implications. To fully account for the impacts of climate change we need to know the human cost of floods and how this cost varies across countries and over time. Second, compared to earthquakes, there is more scope for policy intervention, not only for the mitigation of damage once the flood occurs, but for reducing the intensity of a flood or preventing it entirely.[2] Humans have actively managed rivers and their drainage basins (e.g. through dikes, dams, and levees) for millennia. Land use changes, in particular urbanization and the associated increase in impervious surfaces, and human encroachment into flood plains are thought to contribute to the intensity and frequency of floods (IPCC 2007a, Chapter 3). Therefore, income and institutional variables capturing the ability and effectiveness of the government to provide public services may affect flood mortality both

[2] Most earthquakes are caused by movement of the Earth's tectonic plates. Human activity can also produce earthquakes through the construction of large dams and buildings, drilling and injecting liquid into wells, coal mining and oil extraction, and nuclear tests, but these instances are very rare (Kisslinger, 1976).

directly and indirectly. Directly, through the provision of early-warning information systems to keep people out of harm's way, and disaster-relief and emergency services once the flood occurs. Indirectly, by influencing the probability of occurrence and the magnitude of a flood, through, for example, the enactment and enforcement of zoning regulations and relief cuts and other flood-management-related actions (construction and maintenance of dams, levees, bridges). In our paper we consider both channels.

Our paper improves on previous research designs in two additional ways. First, we control for the physical magnitude of a flood to explain the number of deaths. In an influential paper, O'Keefe et al (1976) emphasize human vulnerability when they discuss "taking the naturalness out of natural disasters." As echoed by Neumayer and Plumper (2007, p 552) "the impacts of natural disasters are never merely determined by nature on its own. Indeed, it becomes even questionable whether one can talk of ‘‘natural’’ disasters at all." However, nature still plays an unquestionable role in the outset of a disaster. Moreover, when the magnitude of an event is potentially correlated with the same socioeconomic variables that determine the vulnerability of the affected population, there is a risk of omitted variable bias. With the exceptions of recent papers on earthquake mortality by Anbarci et al. (2005) Escaleras et al. (2007) and Keefer et al. (2010), most studies do not control for the physical intensity of disasters when studying their impacts. Second, we overlay the maps of the regions affected by flooding with global population maps, and calculate the population exposed to a given flood event using GIS, obtaining as a result, more precise estimates of vulnerability.

We find that population exposure affects the number of deaths both directly, once the flood has occurred, and indirectly, by influencing the size and frequency of floods. More population exposure is associated with more deaths conditional on flood occurrence and controlling for the magnitude of the flood. And because more people increase the potential for damage and deaths, this increases the payoffs of investments in flood mitigation and management, resulting in smaller floods. In developing countries more population exposure is also associated with fewer floods.

Year-to-year changes in income, and in two indices of corruption and ethnic tensions do not significantly affect the number of deaths once the flood has occurred. They influence flood mortality only indirectly, through their impact on the intensity and frequency of floods. Increases in income are associated with less intense and fewer floods, with the latter effect being strongest in developing countries. Improvements in the corruption and ethnic tensions indices are, however, associated with an increase of the magnitude of the flood.

2. Data

We compiled an unbalanced panel with observations on the number of people killed in flood events as well as variables capturing the physical intensity of the flood, exposure and vulnerability of the population affected, for 2,194 floods occurring in over 100 countries during the period 1985-2008. The basic unit of observation is a flood event.

2.1 Flood data

The flood-event related data originates from the publicly accessible Global Archive of Large Flood Events kept by the Dartmouth Flood Observatory (DFO, now at Colorado: http://floodobservatory.colorado.edu). DFO uses a collection of tools to detect and locate flood events, such as MODIS (Moderate Resolution Imaging Spectroradiometer, http://modis.gsfc.nasa.gov) and optical remote sensing, which provide frequent updates of worldwide surface water condition. These are complemented with data derived from a variety of news and governmental sources.

As water bodies are not confined to national boundaries, some floods (slightly fewer than 10 percent of all the floods reported between 1985 and 2008) are regional in scope. The number of deaths registered in the database is the aggregate figure per flood event, with no available split between the countries affected. Thus, we limit our sample to non-regional floods. Deaths recorded in disaster databases are typically from drowning and severe injuries.[3] Table 2 shows that the average number of people killed in a flood event, 119, is large, but much smaller than the variance (a first sign of over-dispersion in this variable). A more detailed look at its frequency distribution in Table 3 shows that the distribution of deaths in floods has a long right tail. The proportion of events with zero deaths is 9.9 percent. More than 90 percent of the values are under 100, and more than 99 percent under 1,000. The very large death toll of 138,000 corresponds to the 1991 Bangladesh cyclone that, in addition, left more than 10 million people homeless.

DFO reports the magnitude of the flood as the log of the product of flood duration (in days)* area affected by the flood * flood severity. Floods are divided into three severity classes depending on their estimated recurrence interval. Class 1 floods have a 10-20 year-long reported interval between similar events, class 1.5 have a 20-100 year recurrence interval, and class 2 have a recurrence interval greater than 100 years.

2.2 Exposure: Population in flooded areas

[3] Deaths from unsafe or unhealthy conditions following the extreme event are also a health consequence but disasters statistics typically include only the deaths recorded while the event is "active" (Combs et al. 1998; Jonkman and Kelman 2005).

Each entry in the DFO's register of major flood events has an associated GIS polygon representing the area affected by that flooding event. DFO uses news and governmental sources to determine this geographic area.

We overlaid flood maps with population maps from the Gridded Population of the World v3 (CIESIN-CIAT 2005) using GIS, to obtain estimates of the population exposed to a flood event. Flood maps are available for each flood event up to year 2008. Population grid maps are available in 5-year intervals since 1990. We calibrated an exponential curve for the remaining years to complete the panel. The resulting estimates of population exposure to a flood are more precise than statistics based on country-average population densities.[4] At the same time, since the areas in DFO's flood maps are broader than the actual inundation sites, they can capture the population that has been displaced. An illustration of the difference between the inundated and affected area is presented in Figure 2. The outline in Panel A shows the area affected by a flooding event, while the red areas, enlarged in Panel B, correspond to the inundated area.

2.3 Vulnerability: Socioeconomic and institutional indicators

The indicator of income is GDP per capita converted to constant 2005 international dollars using purchasing power parity rates. It comes from the World Development Indicators (WDI, 2010).

The institutional indicators are a corruption index and an ethnic tensions index, both from the International Country Risk Guide (ICRG) of Political Risk Services (PRS).[5] The ICRG is a popular source of governance indicators used in cross-country studies. It offers broad country coverage, which reduces the risk of selection bias (Kaufmann et al. 1999; Johnston 2001), and

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[4] For millennia people have tended to concentrate in flood plains. As shown in table 2, in our sample, average population density in areas affected by floods is 394.46 persons/squared km. The average population density based on country statistics is 151.34 persons/squared km.

[5] www.prsgroup.com.

indicators are available for a relatively long time period (1984 to the present), which covers our estimation sample.

Corruption "distorts the economic and financial environment; it reduces the efficiency of government and business by enabling people to assume positions of power through patronage rather than ability; and, [...], introduces an inherent instability into the political process."[6] It is relevant for our analysis as it may influence the creation and enforcement of rigorous building codes, retrofitting of bridges, dams, levees and other structures, zoning regulations (e.g. land-use controls which limit construction in flood plains) and the effective provision of emergency relief services. Higher ratings are given to less corrupt countries.

Anbarci et al. (2005) highlight the ability of a country to pursue collective action as an important factor to fight earthquake mortality. In addition to corruption, we use two variables, ethnic tensions (from PRS) and a GINI indicator (from WDI 2010), to capture this effect. Ethnic tensions represent "the degree of tension within a country attributable to racial, nationality, or language divisions. Lower ratings are given to countries where racial and nationality tensions are high because opposing groups are intolerant and unwilling to compromise. Higher ratings are given to countries where tensions are minimal, even though such differences may still exist."[7] The GINI indicator measures the degree of inequality in the distribution of income within a country.

Socioeconomic and institutional indicators are available at the country-year level. They are matched to the corresponding flood events.

2.4 Other controls

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[6] Excerpts from variable descriptions in IRCG at www.prsgroup.com.
[7] See footnote 6.

We hypothesize that socioeconomic and institutional factors have an indirect effect on flood mortality through their impact on the magnitude and number of floods. To explain magnitude and flood frequency, we also account for a number of physical factors, at the country level, some of them time-invariant. Descriptive statistics of these variables are presented in Table 2.

Precipitation, measured as average precipitation in depth (mm per year), country's total land area (squared km.), and urban population growth come from WDI (2010). Latitude (in absolute value), mean elevation (meters above sea level), and the percentage of land area within 100 km of ice-free coast come from Gallup et al. (1999). More frequent and larger floods are expected, *ceteris paribus*, where there is more rain and more area to be flooded. Latitude, elevation and proximity to the coast are also important determinants of climate systems.

We obtained data on total forest area, measured in thousand hectares and encompassing both natural forests and plantations, for 1990, 2000, and 2005 from FAO (2001, 2005, 2007). We interpolated estimates for other years by calibrating an exponential curve to the three observations for each country. Data were converted to squared km. and expressed as a percentage of total land area. Despite widespread belief that forests can prevent and reduce floods, the effect of forests on the magnitude and the probability of large flood events remains controversial.[8]

3. Estimation strategy

[8] Bradshaw et al. (2007) use DFO flood data to show that forests are correlated with flood risk and severity. Using the same data, Van Dijk et al. (2009) offer an alternative explanation: floods are correlated with population density - an omitted variable in Bradshaw et al. (2007) analysis. In our study we control for both, forest area and population in the flooded area.

We first estimated the number of deaths as a function of the intensity of the flood event, measured by its magnitude; the exposure of the population, measured as the log of the population living in the affected area; and socioeconomic and institutional indicators of vulnerability.

3.1 Direct effects on number of deaths

The dependent variable is the non-negative count of deaths in a flood event. Poisson regression is the standard method used to model count-response data. However, the Poisson distribution assumes the equality of the mean and variance in the number of deaths. The variance of the number of deaths in our sample is much larger than its mean (see Table 2), suggesting that a model that accommodates this overdispersion, such as the Negative Binomial Regression, may be more appropriate.[9] This model generalizes the Poisson by relaxing the assumption of equal conditional mean and variance through the introduction of a parameter that reflects the unobserved heterogeneity between observations in the sample. The regressions reported in the results section below correspond to this model.

With fewer than 10 percent of the observations exhibiting zero deaths, the use of a Zero-Inflated Negative Binomial Regression does not seem warranted. As noted by Keefer et al. (2010) this model assumes that some observations take on a value of zero with probability of one (Long & Freese 2006). This is not a reasonable assumption, given that the sample is restricted to large flood events.

The dataset is an unbalanced panel for the period 1985-2008. Observations within a panel cannot be considered independent, with the within panel correlation also resulting in overdispersed data (Hilbe 2007). In addition, there may be unobserved country effects affecting

[9] We tested the goodness-of-fit of a Poisson regression and obtained a significant test statistic (P-value=0.00) indicating that the Poisson model is inappropriate.

the count of deaths. The models presented in the results section add country-specific effects to the regressions.[10] We report robust standard errors clustered at the country level, but our panel non-linear estimation routine does not correct for potential correlation across panels. We hope that eliminating regional floods from the sample, as discussed in the introduction, may go some way in alleviating the concern that this may underestimate the standard errors (Beck and Katz 1995). Finally, we lag all explanatory variables by one year to mitigate endogeneity bias.

3.2 Flood magnitude and flood frequency

The number of people killed in a flood is conditional on the magnitude of the flood, and on its actual occurrence. In turn, magnitude and the number of floods are modeled as a function of the natural characteristics of the country, and socioeconomic and institutional variables believed to be related to land use and flood management.

Flood magnitude is a continuous variable, and linear regression analysis techniques are appropriate. Data are available at the flood event level, so individual flood events continue to be the unit of analysis. We present results from the pooled as well as country-specific random effects models.[11]

To measure flood frequency, we use the yearly count of floods in a country. By definition, the probability of occurrence of a flood event included in the DFO is one. Thus, we need to change the unit of observation to a country-year instead of a flood event. The average number of floods in a country-year reported in Table 2 is 1.12. The variance is much larger. As with the number of people killed by floods, we are dealing with overdispersed count data. The

[10] A significant likelihood-ratio test statistic (P-value=0.00) lead us to reject a pooled model, while a Hausman test (P-value=0.00) favored a conditional fixed-effects regression.
[11] A significant likelihood-ratio test statistic (P-value=0.00) lead us to reject the pooled model in favor of a random-effects model. We opted for random over fixed effects as the latter would drop the countries' natural characteristics that do not vary over time (e.g. latitude, land area, percentage of coastal land) from the analysis.

same estimation techniques discussed in Section 3.1 are relevant here. In all the regressions we lag the explanatory variables by one year to mitigate endogeneity bias, and report clustered-robust standard errors at the country level.

4 Results

4.1 Direct effects on number of deaths

Table 4 presents the results of the estimation of the number of deaths in flood events. The first column corresponds to a standard negative binomial regression similar to those used to explain earthquake mortality (e.g. Anbarci et al. 2005, Keefer et al. 2010). Observations are pooled and the regression includes continent dummies. Coefficients for all the variables but ethnic tensions are statistically significant at a 5 percent significance level or better.

The results conform to intuition. According to column 1, the larger the flood the larger its death toll. A one unit increase in magnitude is associated with a 55 percent increase in the number of deaths. To give an indication of the (large) size of this effect, at the predicted number deaths of 31, increasing the magnitude of the flood by one would result in 17 additional deaths. Similarly, the more population living in the affected area and exposed to the flood, the larger the death toll; a one percent increase is associated with 7.7 more deaths (25 percent of 31). An increase of one percent in income reduces the death toll by 13 people (44 percent of 31). Corruption increases the number of deaths; an improvement in the corruption index by one reduces the number of deaths by 20 percent. Finally, over time the number of deaths has been falling at a rate of 7 percent (or 2.2 deaths) per year.

Because the sample is restricted to large-flood-event observations, and we are controlling for the magnitude of the flood, results in Table 4 capture the *direct effects* of the variables, once the shock has taken place. The coefficient on income may capture availability of better medical care, emergency treatment and crisis management (Athey and Stern, 2002). In addition, richer nations typically have better forecasting and warning systems. Investment in computer modelling of storms and early warning systems can facilitate mass evacuations and save lives (Sheets & Williams, 2001). The coefficient on corruption may capture better provision of public services, including disaster relief but also the creation and enforcement of rigorous building codes, and maintenance and retrofitting of infrastructure such as bridges, dams and levees.

The second column of Table 4 presents results from the estimation including country fixed effects.[12] Magnitude remains significant and positive, although its size is reduced. A one unit increase in the magnitude of the flood is associated with a 26 percent increase in the number of deaths. Similarly, the larger the population affected, the larger the number of deaths; a one percent increase raises the death toll, now by 6.6 percent. In this specification, neither income nor governance indicators are significant. This suggests that it is the differences in these variables across countries, rather than within country what were driving the results in column (1). That is, once we control for country-specific unobserved factors that are constant over time, the annual change in a country's GDP does not have a statistically significant impact on the number of deaths. Finally, the coefficient on the time variable indicates that the number of deaths is decreasing over time for all the countries, at a rate of 2.6 percent per year. This may reflect faster and better international aid channels over the period considered.

In column (3) we introduce an indicator of flood frequency, the number of previous flood events in the country. Keefer et al. (2010) find earthquake propensity to be an important determinant of earthquake mortality. Frequent natural disasters increase the payoffs of mortality

[12] Appendix Table 1 decomposes the standard deviations for the independent variables into their within-country and between-country components. Although the within-country standard deviations are smaller than the between-country components except for the population variable, they represent a sizeable fraction of the overall deviation (over 50 percent for all the variables, except for income, for which it is 20 percent). A substantial portion of the variation in independent variables thus remains even when fixed effects are added, as in columns (2) -(7) in Table 4.

prevention. In addition, there could be "learning-by-doing" effects from previous experience with emergency situations. We find that experiencing one additional previous flood reduces mortality by 0.2 percent, and this effect is significant at a 10 percent level. In the same regression, the time trend is now significant only at a 16 percent level.[13]

There are only 47 countries that have more than one observation of the GINI index allowing for a fixed-effects estimation. Despite the reduction in the sample size, the results are robust to the inclusion of this variable, although the coefficient on population is now significant only at a 20 percent level. The coefficient on the GINI index itself has a positive sign implying that more inequality is associated with more deaths, supporting the argument in Anbarci et al (2005), but this effect is only significant at a 20 percent level.

The DFO records the cause of the flood for most of the events. In column (5) we restrict the sample to events caused by "heavy rain" so that we exclude instances of "mal-adaptation" due for example to dam breaks. This sample also excludes floods caused by ice-melt, cyclones (such as the 1991 Bangladesh cyclone), tidal surges and tsunamis.[14] Results are robust, and the effects of magnitude, population exposure and time are slightly larger than in the baseline specification.

A caveat noted explicitly by the DFO is that the quality of the flood-event information varies from nation to nation: "[N]ews from floods in low-tech countries tend to arrive later and be less detailed than information from 'first world' countries." In addition, less democratic countries may systematically underreport the number of casualties. Both these effects are captured by the country-specific effects as long as they are constant over time. If reporting improves over time, however, country fixed effects will not pick up the differences in reporting.

[13] The correlation between the two is 0.41.
[14] We also estimated a model targeting outlier observations explicitly. The results did not change when we omitted flood events with more than 1,000 casualties.

Alternatively, we could repeat the estimation with only the most recent, most accurate, observations. Column (6) reports the results of the estimation covering the last 10 years. The impacts of population exposure and time are larger, but otherwise the results are robust.

Finally, we estimated the model for the "low tech" (developing) countries. The most significant change with respect to the baseline is that in column (7), income has a positive impact (significant at a 10 percent level) on flood mortality. Given that we are controlling for magnitude, population exposed, and institutional variables, this result is consistent with higher income resulting in more exhaustive reporting of deaths in developing countries.

4.2 Flood magnitude

We hypothesize that income and the institutional characteristics of a country have an indirect impact on flood mortality, by influencing the magnitude and frequency of floods.

The magnitude and frequency of floods do not only depend on the amount of precipitation and physical characteristics of a given area. Table 5 suggests that socioeconomic factors associated with land use and flood management also play an important role. In column (1), precipitation is not significant, but the ethnic tensions index and population living in the area are. A caveat of our precipitation variable is that it is only available for the year 2008 for 53 observations in our sample. In columns (2)-(7) we omit the precipitation variable. We do not believe that this omission will bias the results. Table A2 shows that other physical controls (latitude, the percentage of land area close to the coast, forested area, elevation, total area and continent dummies) explain 73 percent of the variation in the precipitation variable.

The results of the pooled model are presented in column (2). In column (3) we introduce country-specific effects. Results suggest that larger countries experience larger floods as do countries with more coastal land (this second effect is no longer statistically significant after introducing country-specific effects). More population reduces the magnitude of the flood. A one percent increase in population is associated with a reduction in magnitude of 0.14 percentage points. This is a modest impact, but it is highly significant, robust across specifications, and of the expected sign. More people means more hands to fight a flood. More people also means a higher exposure and potential for damage and deaths (as shown in Table 4). This increases the payoffs of investments in flood mitigation and management.

Income also has a negative impact on flood magnitude (a one percent increase in income is associated with around 0.2 percentage points lower magnitude) possibly reflecting more resources available for flood control. Interestingly, the indices of corruption and ethnic tensions exhibit a positive sign. A reduction in the obstacles for collective action and efficient provision of public services associated with an increase of the magnitude of the flood. At first sight this may seem counterintuitive, but it might reflect a different approach to flood management: "learning to live with the floods" rather than "fighting the floods" through infrastructural solutions. For example, flood storage could become a recognized land use in development plans, which could be encouraged and compensated through government incentives. This kind of arrangement is more likely, *ceteris paribus*, in less corrupt and less fractioned societies. Galloway (1999) reports that over 25,000 homes have been relocated from the Mississippi floodplain since the large floods of 1993, and thousands of hectares of marginally productive low-lying areas have been reconverted from agriculture to natural areas. These actions seek to reduce the impacts on a population, but translate into large areas being flooded which, in turn, increase our measure of the magnitude of a flood.

In column (4), the coefficient on flood frequency indicates that experiencing one additional previous flood is associated with a larger flood, although the size of this effect

(0.0015) is small. In the same specification, the coefficient of year is negative and significant indicating that floods are becoming smaller over time. This reduction in flood magnitude through time has been particularly strong in developing countries (column 7), but it seems to have happened in the earlier years of the time period considered. Over the last 10 years, flood magnitude is positively associated with time, increasing at a rate of 0.06 per year.

Unlike Bradshaw et al. (2007) we do not find evidence that forests reduce the magnitude of the flood. The percentage of forested area is not significant in any of the specifications. Our variable capturing the urbanization trends does not have a significant impact on flood size either.

4.3 Flood frequency

To assess the relative importance of socioeconomic factors in explaining the number of floods we turn to Table 6. The first column presents the results of a pooled negative binomial regression. The count of floods in a year is larger, *ceteris paribus*, in larger countries. A one percent larger land area is associated with 21 percent more floods. At the predicted number of floods of 0.55, this would result in 0.11 additional floods. Countries with more coastal land also experience, *ceteris paribus*, more floods. Having a one percent more coastal land is associated with 0.40 more floods (74 percent of 0.55). Increasing the percentage of forested land by one percent is associated with 0.60 fewer floods. This result is in line with those in Bradshaw et al. (2007) but it is not robust to the inclusion of country-specific effects. The year-to-year change in the percentage of forested area within a country in columns (2)-(5) is not significantly associated with a change in the number of floods.

Population has a significant, positive impact on the number of floods recorded, according to column (1). Larger countries in terms of population[15] (not only land area) experience more floods. The coefficient, however, switches signs when we control for country fixed effects and it is significant for developing countries. In these countries, the year-to year increase in population is associated with a reduction in the number of floods, suggesting that the larger the population, the stronger the incentives for flood prevention. Similarly, in columns (2), (3), and, more markedly, (5), income exhibits a negative and statistically significant coefficient. Inter-annual increases in income within a country are associated with a decrease in the number of floods, possibly due to increased availability of resources for flood management. This effect is strongest in developing countries. In these countries, reducing corruption is associated with a reduction in the number of floods, although this effect is not as strong as the effect of increasing income, either statistically or economically.

The most robust result across specifications and subsamples is that the number of floods is increasing over time at a rate of around 5 percent per year, with a larger effect, again, in developing countries.

5. Conclusions

In this paper we use new data on large flood events between 1985 and 2008 in over 100 countries to investigate the relative contribution of natural and socioeconomic factors to explain the number of people killed by floods.

The physical magnitude of a flood has a large, positive and robust impact on the number of deaths. This is hardly surprising; larger floods kill more people. More surprising is that,

[15] The population variable in Table 6, unlike those in Tables 4 and 5, does not refer to the population in flooded areas. It refers to the average population in the country, since the unit of analysis is the country-year.

conditional on flood occurrence and controlling for flood magnitude, year-to-year changes in income, and in two indices of corruption and ethnic tensions do not significantly affect the number of deaths.

Higher incomes enable investment in better monitoring and early warning systems, in infrastructural solutions for flood management, and, once the flood has occurred, in faster and better emergency assistance. Lower corruption and more social cohesion facilitate the provision of those public services more effectively, and the creation and enforcement of rigorous building codes and land zoning restrictions. Our results suggest that these factors help explain differences in deaths between countries, as previous research has shown for other natural disasters. Within a country, however, after controlling for flood occurrence and intensity, annual changes in incomes or institutions do not directly affect the death toll.

This does not mean that socioeconomic factors do not matter. Income and institutions influence flood mortality indirectly, through their impact on the intensity and frequency of floods. For millennia, humans have settled close to water bodies and in flood plains, and actively managed rivers and their drainage basins, willingly (e.g. through dikes, dams, and levees), or unwillingly. Inter-annual increases in income within a country are associated with a lower flood magnitude and a decrease in the number of floods, possibly reflecting more resources available for flood control and management. This effect is strongest in developing countries, as they may have more scope for improvement, but modest overall. Interestingly, a reduction in the obstacles for collective action and efficient provision of public services (as measured by the corruption and ethnic tensions indices) are associated with an increase of the magnitude of the flood. We hypothesize that this could be due to a "learning-to-life-with-the-flood" management approach, in which development plans result in the creation of large flood storage areas as an alternative land use. These actions seek to reduce the impacts of a flood on a population, and are often accompanied with the relocation of homes, but translate into large areas being flooded which, in turn, increase the measure of the magnitude of a flood.

Population exposure affects the number of deaths both directly and indirectly. We obtain estimates of the population exposed to a flood event by overlying maps of the areas affected by floods with global population maps using GIS. Higher population exposure is associated with more deaths once the flood has occurred. However, precisely because more people increase the potential for damage and deaths, this increases the payoffs of investments in flood mitigation and management, resulting in smaller floods. In developing countries more population exposure is also associated with fewer floods.

Our paper also contributes, albeit tangentially, to the debate of the role of forests on the prevention and reduction of large flood events. We do not find evidence that forests reduce the magnitude of large flood events. Year-to-year changes in forested area do not significantly affect the number of floods experience by the countries in our sample either.

Finally, our results suggest that the number of deaths is decreasing over time for all the countries, at a rate of 2.6 percent per year, which may reflect faster and better international aid channels. Unfortunately, results also show that the number of floods is increasing over time, and that, over the last 10 years, floods are becoming larger.

Table 1: Immediate impacts of disaster (1985-2009), by disaster type

Panel A	**Absolute number**			
	Number of events	People dead	People affected (million)	Damages 2009 (mill. US$)
Floods	2893	175453	2,677	7,723
Storms	2251	414425	722	24,641
Extreme temperature	339	101638	92	1,162
Earthquakes	656	601032	136	6,059
Droughts	352	7512	1,425	29
Other	829	47825	16	1,669
Total	7,320	1,347,885	5,068	41,282

Panel B	**Percentage of total**			
	Number of events	People dead	People affected	Damages 2009
Floods	40	13	53	19
Storms	31	31	14	60
Extreme temperature	5	8	2	3
Earthquakes	9	45	3	15
Droughts	5	1	28	0
Other	11	4	0	4

Source: EMDAT, the OFDA/CRED International Disaster Database (www.emdat.be), Universite Catholique de Louvain, Brussels, Belgium (Data version: v12.07, 2010).

To be included in the database, an event needs to fulfill at least one of the following criteria: (i) 10 or more people killed, (ii) 100 or more people reported affected (typically displaced); (iii) a declaration of a state of emergency; (iv) a call for international assistance.

The "Other" category includes wildfires, wet and dry mass movements (landslides, avalanches, etc.), and volcanoes. People dead include persons confirmed as dead and persons missing and presumed dead. People affected are those requiring immediate assistance during a period of emergency, i.e. requiring basic survival needs such as food, water, shelter, sanitation and immediate medical assistance.

Table 2: Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
Flood events between 1985 and 2008 (N=2,194)				
Number of deaths	119	2961	0	138,000
Flood magnitude	5.17	1.10	1.30	8.37
Pop. Density flooded area	394.46	1275.04	0.02	30,823
Country-year statistics (n=108 countries)				
GDP per capita (PPP 2005$)	9,375	10,190	203	47,996
Corruption	2.88	1.21	0.00	6.00
Ethnic tensions	3.82	1.46	0.00	6.00
Gini coefficient	45.32	9.44	24.85	62.99
Precipitation (mm.)	1,172	765	89	2,702
Total area (square km)	1.89E+06	3.18E+06	1.04E+03	1.64E+07
Urban population growth (%)	2.60	1.68	-2.77	12.83
Latitude (absolute value)	24.25	15.68	0.42	67.47
Elevation (meters)	649	423	18	1,871
Coastal land (% total area)	0.37	0.34	0	1
Forest area (% total area)	0.30	0.19	0.0000646	0.95
Count of floods	1.12	2.55	0	32

Source: DFO for flood related data (deaths, magnitude, flooded area); Gridded Population of the World v3 (CIESIN/CIAT 2005) for population in flooded areas; WDI (2010) for GDP per capita; PRS for Corruption and Ethnic tensions. Flood magnitude = log(affected area*flood duration * flood severity). See text for detailed description of variables.

Table 3: Frequency distribution of number of deaths per flood event

Number of deaths	Freq.	Percent	Cum.
0	218	9.94	9.94
1 - 5	644	29.35	39.29
6 - 10	277	12.63	51.91
11 - 20	330	15.04	66.96
21 - 50	342	15.59	82.54
51 - 100	172	7.84	90.38
101 - 1000	200	9.12	99.5
1001 - 138000	11	0.5	100
Total	2,194	100	

Source: DFO (2010)

Table 4: Determinants of flood mortality

	Pooled	Controlling for country-specific effects					
		Baseline	Frequency	Gini	Heavy Rain	Last 10 years	Developing countries
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Magnitude	0.554***	0.255***	0.272***	0.238***	0.320***	0.241***	0.251***
	(0.0540)	(0.0335)	(0.0327)	(0.0487)	(0.0262)	(0.0368)	(0.0383)
Ln(population)	0.250***	0.0657**	0.0730***	0.0869	0.0994***	0.108***	0.0533*
	(0.0490)	(0.0264)	(0.0255)	(0.0691)	(0.0180)	(0.0246)	(0.0304)
Ln(GDP per capita PPP)	-0.437***	0.0755	0.112	0.0736	0.0992	0.00428	0.238*
	(0.0953)	(0.0980)	(0.0825)	(0.217)	(0.0657)	(0.143)	(0.123)
Corruption	-0.202**	0.0381	0.0324	0.00684	-0.0107	-0.0745	0.104
	(0.0967)	(0.0682)	(0.0684)	(0.0791)	(0.0496)	(0.0804)	(0.0777)
Ethnic tensions	-0.0127	0.0250	0.0364	0.0319	0.00625	0.0592	-0.000193
	(0.0638)	(0.0328)	(0.0347)	(0.0702)	(0.0425)	(0.0486)	(0.0359)
Year	-0.0707***	-0.0261***	-0.0147	-0.0328***	-0.0343***	-0.0497***	-0.0267***
	(0.0133)	(0.00703)	(0.0104)	(0.0113)	(0.00539)	(0.0129)	(0.00572)
Frequency			-0.00238*				
			(0.00136)				
Gini				0.0161			
				(0.0123)			
Continent dummies	Yes	No	No	No	No	No	No
Country F.E.	No	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2194	2178	2178	371	1404	1166	1627
Number of id	108	93	93	47	88	79	72

Notes: Negative binominal regressions. Dependent variable is number of people dead in flood event. Cluster-robust standard errors (country-level) in all specifications. In (2)-(6) a cluster bootstrap was performed. *** p<0.01, ** p<0.05, * p<0.1.

Table 5: Determinants of flood magnitude

	Pooled	Pooled	Controlling for country-specific effects				
			Baseline	Frequency	Heavy rain	Last 10 years	Developing
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Precipitation	0.000512						
	(0.000492)						
Ln(area)	-0.0820	0.114***	0.184***	0.166***	0.157***	0.224***	0.185***
	(0.245)	(0.0401)	(0.0388)	(0.0395)	(0.0454)	(0.0497)	(0.0389)
Forest (%)	-2.745	-0.179	0.0638	0.0586	-0.0457	-0.0361	-0.0630
	(1.975)	(0.252)	(0.239)	(0.241)	(0.269)	(0.330)	(0.267)
Urban pop.	-0.535	-0.0597	0.0141	0.00982	0.0122	-0.0791	-0.0200
growth	(0.358)	(0.0437)	(0.0296)	(0.0295)	(0.0370)	(0.0544)	(0.0315)
Elevation	0.000130	-3.08e-05	-0.000140	-0.000154	-9.29e-07	-0.000134	-0.000189
	(0.000606)	(7.71e-05)	(0.000132)	(0.000134)	(0.000145)	(0.000183)	(0.000130)
Latitude	0.0321	-0.00318	-0.00150	-0.00140	-0.00422	-0.00527	0.00131
	(0.0190)	(0.00411)	(0.00434)	(0.00439)	(0.00492)	(0.00594)	(0.00496)
Coastal (%)	0.00425	-0.406*	-0.0781	-0.113	-0.157	0.0650	-0.0690
	(1.186)	(0.223)	(0.192)	(0.193)	(0.217)	(0.240)	(0.194)
Ln(population)	-0.325***	-0.141***	-0.138***	-0.140***	-0.154***	-0.139***	-0.168***
	(0.0821)	(0.0270)	(0.0164)	(0.0165)	(0.0199)	(0.0201)	(0.0202)
Ln(GDP per	-0.143	-0.249***	-0.183***	-0.199***	-0.135**	-0.213**	-0.142**
capita PPP)	(0.365)	(0.0510)	(0.0547)	(0.0549)	(0.0634)	(0.0834)	(0.0564)
Corruption	-0.00531	0.0720**	0.0812***	0.0885***	0.0907***	0.0471	0.101***
	(0.149)	(0.0343)	(0.0275)	(0.0274)	(0.0325)	(0.0499)	(0.0309)
Ethnic tensions	-0.349*	0.0449	0.0400*	0.0359	0.0566**	0.0732*	0.0219
	(0.171)	(0.0306)	(0.0239)	(0.0238)	(0.0285)	(0.0437)	(0.0248)
Year		-0.00965	-0.00464	-0.0122**	-0.00587	0.0645***	-0.0139***
		(0.00852)	(0.00411)	(0.00531)	(0.00520)	(0.0123)	(0.00487)
Frequency				0.00146**			
				(0.000676)			
Continent dummies	Yes	Yes	No	No	No	No	No
Country-specific (Random) Effects	No	No	Yes	Yes	Yes	Yes	Yes
Observations	53	2188	2188	2188	1435	1185	1661
Number of id		108	108	108	101	98	85

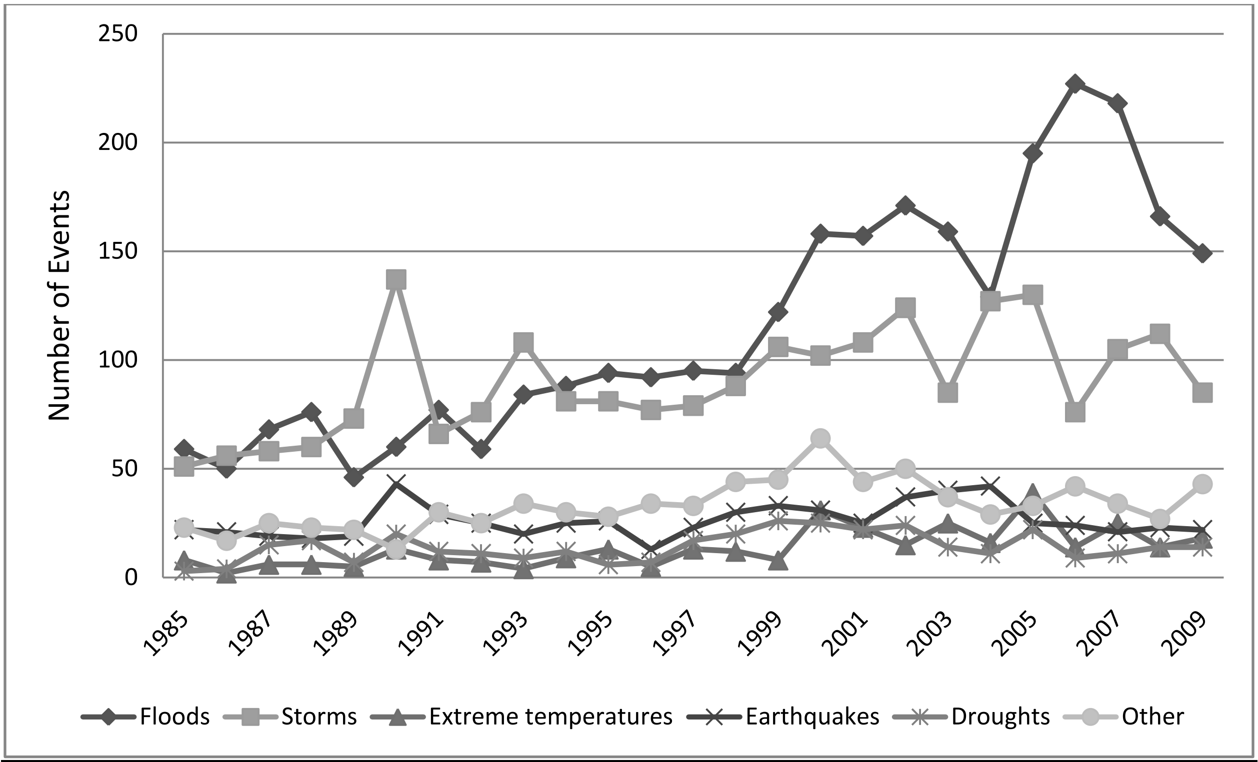
Notes: Dependent variable is flood magnitude. Cluster-robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Explaining number of floods

	Pooled	Controlling for country specific effects			
		Baseline	Frequency	Last 10 years	Developing
VARIABLES	(1)	(2)	(3)	(4)	(5)
Ln(area)	0.208***	0.182	0.166	-0.0143	0.413*
	(0.0587)	(0.165)	(0.177)	(0.491)	(0.220)
Forest (%)	-1.091***	-0.00183	0.242	-1.658	-0.0115
	(0.324)	(0.713)	(0.762)	(1.576)	(0.968)
Urban pop. growth	0.00280	0.0408	0.0607	0.167	0.0176
	(0.0503)	(0.0462)	(0.0473)	(0.110)	(0.0510)
Elevation	-0.000101	0.00118**	0.00108**	0.00142	0.00139***
	(0.000153)	(0.000473)	(0.000466)	(0.000903)	(0.000475)
Latitude	-0.00349	-0.00833	-0.00106	-0.00262	-0.0273*
	(0.00550)	(0.0118)	(0.0125)	(0.0183)	(0.0162)
Coastal (%)	0.741***	1.110	1.009	1.216	0.624
	(0.225)	(0.811)	(0.855)	(2.040)	(1.159)
Ln(population)	0.570***	-0.182	-0.312	-0.370	-0.649***
	(0.0642)	(0.176)	(0.196)	(0.297)	(0.249)
Ln(GDP per capita PPP)	0.0605	-0.225*	-0.262*	-0.0331	-0.599***
	(0.0716)	(0.134)	(0.151)	(0.280)	(0.177)
Corruption	0.0103	-0.0533	-0.0555	-0.0841	-0.0667*
	(0.0508)	(0.0361)	(0.0373)	(0.0692)	(0.0401)
Ethnic tensions	-0.112***	-0.0109	-0.00666	-0.0190	0.00420
	(0.0323)	(0.0310)	(0.0316)	(0.0611)	(0.0333)
Year	0.0426***	0.0585***	0.0587***	0.0478***	0.0751***
	(0.00635)	(0.00744)	(0.00802)	(0.0184)	(0.0101)
Frequency			0.0219***		
			(0.00785)		
Continent dummies	Yes	No	No	No	No
Country Specific Fixed Effects	No	Yes	Yes	Yes	Yes
Observations	2292	2292	2138	990	1782
Number of id	107	107	107	107	84

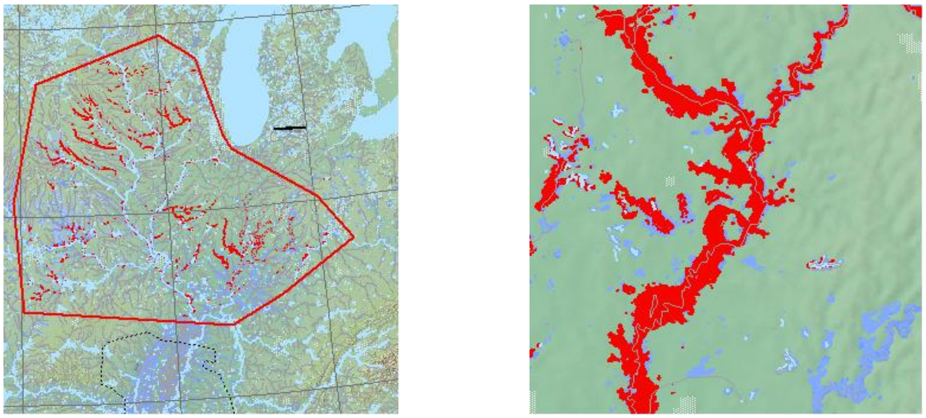
Notes: Negative binominal regressions. Dependent variable is number of people dead in flood event. Cluster-robust standard errors (country-level) in all specifications. In (2)-(5) a cluster bootstrap was performed. *** p<0.01, ** p<0.05, * p<0.1.

Figure 1: Incidence of natural disasters 1985-2009



Source: EMDAT, the OFDA/CRED International Disaster Database (www.emdat.be), Universite Catholique de Louvain, Brussels, Belgim (Data version: v12.07, 2010). The "Other" category includes wildfires, wet and dry mass movements (landslides, avalanches, etc.), and volcanoes.

Figure 2: Difference between affected area (Panel A) and inundated land (Panel B)



Panel A Panel B

Source: Brakenridge and Hopson (2010).

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Appendix

Table A1: Decomposition of standard deviation of key explanatory variables

	Overall	Between	Within
Magnitude	1.101	0.727	0.982
Ln(population)	1.848	1.678	1.392
Ln (GDP per capita PPP)	1.259	1.279	0.241
Corruption	1.281	1.149	0.739
Ethnic tensions	1.418	1.348	0.737

N = 2,194; n=108; Sample period: 1985-2008.

Table A2: Precipitation regression

VARIABLES	(1) rainmm
Ln(area)	-56.86**
	(22.94)
Forest (%)	988.9***
	(179.9)
Elevation	0.0286
	(0.0587)
Latitude	-20.47***
	(3.760)
Coastal (%)	525.8***
	(155.8)
Continent dummies	Yes
Observations	140
R-squared	0.730

Sample is140 countries for year 2008
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1