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Nature, Socioeconomics and Adaptation to Natural Disasters

New Evidence from Floods

Susana Ferreira
Kirk Hamilton
Jeffrey R. Vincent

The World Bank
Development Research Group
Environment and Energy Team
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Abstract

The authors analyze the determinants of fatalities in 2,194 large flood events in 108 countries between 1985 and 2008. Given that socioeconomic factors can affect mortality right in the aftermath of a flood, but also indirectly by influencing flood frequency and magnitude, they distinguish between direct and indirect effects of development on flood mortality. The authors find that income is negatively associated with the frequency of floods and, conditional on their magnitude, the fatalities they cause in developing countries. However, for developed countries they find that increased income is associated with more fatalities, both directly (conditional on flood occurrence and magnitude) and indirectly through an increase in the frequency and magnitude of flood events. Also in contrast to the literature, they find that the effect of governance on flood frequency and fatalities in developing countries is U-shaped, with improvements in governance reducing the numbers of floods and deaths when governance is weaker but raising them when governance is stronger.

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Nature, socioeconomics and adaptation to natural disasters: new evidence from floods

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Susana Ferreira*
(University of Georgia)

Kirk Hamilton
(The World Bank)

Jeffrey R. Vincent
(Duke University)

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* Corresponding author: sferreir@uga.edu.
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1. Introduction

Recent studies have analyzed the role of socioeconomic factors in determining fatalities from natural disasters (Kahn 2005, Kellenberg and Mobarak 2008, Cavallo and Noy 2010),[1] earthquakes in particular (Anbarci et al. 2005, Escaleras et al. 2007, Cavallo et al. 2010, Keefer et al. 2010). An appealing and intuitive general finding from these studies is that countries that are richer and have stronger institutions suffer fewer deaths from natural disasters, as they are evidently better able to agree on, invest in, and enforce zoning regulations, building codes, and other preventive measures.

In this paper, we analyze new data on 2,194 flood events in 108 countries during 1985-2008, and our results tell a very different story. Although we find that income is negatively associated with the frequency of floods and, conditional on their magnitude, the fatalities they cause in developing countries, we find that it increases flood frequency, magnitude, and fatalities in developed countries. Also in contrast to the literature, we find that the effect of governance is not uniformly salutary. Its effect on flood frequency and fatalities in developing countries is U-shaped, with improvements in governance reducing the number of floods and deaths when governance is weaker but raising the number when governance is stronger. We find no evidence that governance affects flood magnitude in developing countries or flood frequency, magnitude, or fatalities in developed countries.

[1] Destructive natural events occur regularly across the world, although most do not cause enough damage to be considered natural disasters. To be included in the widely used 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, or (iv) a call for international assistance (OFDA/CRED 2010).

These results are not a trivial exception to past findings. Floods were the most common natural disaster between 1985 and 2009, accounting for 40 percent of the total number of events, more than half of the number of people affected (including more than a tenth of those killed), and the bulk of economic damages (Table 1). Of all natural disasters over the last 25 years, their frequency has increased most rapidly (Figure 1). This rapid increase has been linked to climate change and is expected to become more pronounced over this century (IPCC 2001; Wetherald and Manabe 2002; Emanuel 2005; Swiss Re 2006; IPCC 2007a; Table SPM2 IPCC 2007b). There is general agreement that the impacts of climate change will be larger in poorer countries (Tol 2008), which have greater exposure to climate change, particularly in agriculture and water resources, and lower adaptive capacity (Adger 2006; Smit and Wandel 2006; Tol and Yohe 2007). Already during the last 25 years, over 95 percent of the deaths caused by large floods were recorded in developing countries (DFO 2010), which was higher than their shares of flood events and population (77 and 84 percent, respectively).

Nearly all previous economic studies on disasters have drawn data from the Emergency Events Database (Cavallo and Noy 2010), which is affiliated with the World Health Organization and several other international organizations (EM-DAT; www.emdat.be). Though widely used, EM-DAT has shortcomings that include multiple, separate events being recorded as a single one and underreporting of smaller events in developing countries (Jonkman 2005, p. 153). Our flood data originate instead from the Dartmouth Flood Observatory's (DFO) Global Archive of Large Flood Events, which is housed at the University of Colorado (floodobservatory.colorado.edu). The DFO is funded by NASA and the European Commission. It uses a collection of tools to detect and locate flood events, especially remotely sensed data from NASA, the Japanese Space Agency, and the European Space Agency, which provide frequent updates of worldwide surface water conditions. It records floods with "significant damage to structures or agriculture, long (decades) reported intervals since the last similar event, and/or fatalities." The DFO Archive is used more often than EM-DAT by flood researchers, as it provides more detail on flood events, including flood magnitude and GIS data on specific areas affected within a given country, and has a reputation for strong quality control.

In addition to exploiting a new data source, we take steps to identify the effects of income and governance more rigorously than previous disaster studies have. Although most studies have analyzed panel data, only one has exploited this data structure to include country and year effects that control for unobserved heterogeneity in spatial and time dimensions (Kellenberg and Mobarak 2008). The exception separately analyzed country-level data on fatalities caused by earthquakes, landslides, windstorms, and extreme temperature in addition to floods, and unlike our study it found that income had an inverted U-shaped impact on flood fatalities. It excluded governance indicators, however, so this effect might not be an unbiased estimate of the income effect. Several other studies have included both income and governance but not country or year effects (Kahn 2005 for the same five types of disasters; Anbarci et al. 2005 and Keefer et al. 2010 for earthquakes). Kahn applied instrumental variables to a subsample of the countries in his model, but this caused all the income and governance variables to become insignificant at 5%, and not just because the standard errors rose. Keefer et al. allowed income and governance to have nonlinear effects, but not in the same model.

Our models include country and year effects and allow income and governance to have nonlinear effects in the same model. The usual reason economists are reluctant to include country effects in panel models is concern that governance indicators exhibit too little within-country variation to permit identification of their effects. The indicators in our sample exhibit substantial variation within countries, and this enables us to identify highly significant effects of both income and governance, not just one or the other, in several models. As mentioned earlier, these effects evidently differ between developing and developed countries, which is important given that floods have a disproportionate impact in developing countries. These differences are broadly consistent with concerns raised by hydrologists about flood management practices in developed countries, especially the United States.

2. Models

Income and governance might affect flood fatalities through a variety of indirect and direct pathways (Table 2). They might affect it indirectly through an impact on the number of floods, by facilitating the construction, maintenance, and retrofitting of bridges, dams, levees, and other flood-management infrastructures and by facilitating the adoption and monitoring of zoning regulations, as land use can affect flooding risks (upper left-hand cell in Table 2). For example, regulations that reduce the expansion of impervious surfaces could result in less frequent flooding. Income and governance might also influence the effectiveness and celerity of flood management actions that affect the magnitude of flooding, through dam releases and the use of sandbags (lower left-hand cell). The DFO data enable us to estimate models for both the frequency and magnitude of floods.

Once a flood has taken place (that is, conditional on occurrence and magnitude), income and governance might affect the number of casualties by keeping people out of harm's way (upper right-hand cell). Zoning regulations limiting construction and settlement into flood plains can do this preemptively. Likewise, monitoring and information systems can facilitate evacuation from high-risk areas before flooding occurs. A well-functioning emergency and healthcare system can reduce the number of casualties after the flood has occurred (lower right-hand cell).

2.1 Flood frequency

We measure flood frequency by the number of floods (*F*) in country *j* in year *t*. We model it as a function of population exposure, measured by the country's population (*Pop*); two socioeconomic indicators of vulnerability, income per capita (*Y*) and governance (*G*); the natural characteristics of the country (**Z**); unobserved effects for countries (c_j) and years (θ_t); and an error term (u_{jt}):

$$F_{jt} = f(Pop_{jt-1}, Y_{jt-1}, G_{jt-1}, \mathbf{Z}_{jt}, c_j, \theta_t, u_{jt}) \quad (1)$$

All the explanatory variables except the natural characteristics of the country are lagged one period to mitigate potential endogeneity bias.

Natural characteristics of a country that could be correlated with flood frequency include total land area, precipitation, latitude, elevation, and proximity to the coast. More frequent floods are expected, *ceteris paribus*, where there is more area to be flooded and more rain. Latitude, elevation, and proximity to the coast are also important determinants of climate systems. These variables are all time-invariant, so they drop out of models that include country effects, which capture their effects and the effects of other fixed country characteristics. The year effects control for time-varying factors that affect all countries, such as changes in reporting in the DFO archive.[2]

We also include in **Z** two proxies for land-use patterns: the percentage of urban population and total forest area. Increased urbanization and the related increase in impervious surfaces are believed to exacerbate flooding. Despite widespread belief that forests can prevent and reduce floods, the effect of forests on the probability and magnitude of flood events remains controversial (FAO and CIFOR 2005). Bradshaw et al. (2007) used global flood data to show that forests are associated with lower flood risk and severity. Using the same data, Van Dijk et al. (2009) offered an alternative explanation: floods are correlated with population exposure, which Bradshaw et al. omitted. We therefore control for both forest area and population.

Equation (1) is our benchmark specification, but we consider variants with additional controls. We add domestic credit to the private sector to capture access to private investments in self-protection against flooding. We include a Gini coefficient to capture the degree of inequality in the distribution of income within a country, which Kahn (2005) and Anbarci et al. (2005) found to be an important factor explaining earthquake fatalities. Gini values range from zero to one, with values closer to one indicating greater inequality. Finally, as in Kellenberg and Mobarak (2008), we allow for potential nonlinear effects of income through a quadratic specification. We also allow for nonlinear effects of governance, which resource economics studies outside the realm of natural disasters have found to be significant (e.g., Ferreira and Vincent 2010).

[2] An alternative approach for addressing potential changes in data quality is to limit the sample to only recent years, which Wheeler (2010) does in a study based on EM-DAT data. This is a less desirable approach in our analysis, given that we rely on within-country variation to identify the effects of income and governance in our fixed-effects models.

2.2 Flood fatalities

Unlike equation (1) and most previous papers on natural-disaster fatalities, the unit of analysis in our model of the number of people killed (*D*) is not country-year but rather an individual disaster,[3] in our case a particular flood event *i* in a given country and year. The benchmark specification parallels equation (1), with v_{ijt} now used to denote the error term:

$$D_{ijt} = g(Pop_{ijt-1}, Y_{jt-1}, G_{jt-1}, \mathbf{Z}_{jt}, c_j, \theta_t, v_{ijt}) \quad (2)$$

One difference is that Pop_{ijt} is now event-specific. As described later, we generated this variable by overlaying the area of a country affected by a particular flood event with a global population map. Income per capita and the governance indicators are only available at the country-year level, so they are matched more coarsely to the corresponding flood events. For the same reason as in equation (1), we lag all the explanatory variables except a country's natural characteristics.

In addition to event-specific deaths, the DFO provides a measure of the physical magnitude of each flood event (*M*). This variable enables us to decompose equation (2) into two components. The first is a model of the effects of income and governance on deaths, conditional on flood magnitude:

$$D_{ijt} = h(M_{ijt}, Pop_{ijt-1}, Y_{jt-1}, G_{jt-1}, c_j, \theta_t, w_{ijt}) \quad (3)$$

w_{ijt} is the error term. This equation isolates the direct effects of the variables, as shown in the right-hand side of Table 2.[4] The second is a model of effects on flood magnitude:

[3] Kahn (2005) analyzed death and destruction caused by individual earthquakes but not other individual disasters.
[4] We cannot distinguish between the preemptive and reactive channels highlighted in Table 2, as we do not have data on the quality of the emergency services, early warning systems, or specific zoning and building regulations.

$$M_{ijt} = l(Pop_{ijt-1}, Y_{jt-1}, G_{jt-1}, \mathbf{Z}_{jt}, c_j, \theta_t, z_{ijt}) \qquad (4)$$

z_{ijt} is the error term. Like equation (1), this focuses on the variables' indirect effects, but on magnitude instead of frequency.

As with equation (1), we consider variants of equations (2)-(4) that include private credit, the Gini coefficient, and quadratic values of income and governance.[5]

3. Data

We compiled an unbalanced panel with observations on the number of people killed in flood events, as well as variables capturing the physical magnitude of floods and the affected population's exposure and vulnerability, for 2,194 floods in 108 countries during 1985-2008.

3.1 Flood data

We coded the dependent variable in equation (1), F_{jt}, as zero if the DFO reported no floods in a country in a given year. Otherwise, we set it equal to the sum of reported events for that year. On average, there was just over one flood per country-year in the sample (Table 3), but the number varied considerably, as the standard deviation was more than twice the mean. More than half (57%) of the observations equaled zero.

Flood deaths recorded in disaster databases, including the DFO's, are typically from drowning and severe injuries. Deaths from unsafe or unhealthy conditions following a flood are also a health consequence, but disaster statistics typically include only the deaths

[5] Some previous studies on disaster fatalities have also included a variable representing the frequency of disasters, typically calculated as the sum of previous events. Keefer et al. (2010) found that earthquake frequency reduces fatalities, and they argued that more frequent earthquakes increase the payoffs to fatality prevention measures. This may be so, but the results presented in this paper refer to models that exclude such a variable because the country fixed effects in those models should capture cross-country differences in flood frequency. As a test of this, we added the cumulative number of floods to the fatality models, and we found that it was insignificant and had little impact on other coefficient estimates.

recorded while the event is "active" (Combs et al. 1998; Jonkman and Kelman 2005). Most events in our sample killed at least one person, as the proportion of events with zero deaths was just 9.9 percent. Table 3 shows that the mean number killed was large, 119, with great variation: the standard deviation was more than 20 times as large. The frequency distribution of this variable shows that the large mean and standard deviation are due to a long right tail, as more than 90 percent of the values are under 100. One particular event, flooding from a 1991 Bangladesh cyclone that had a death toll of 138,000, has an especially large impact on the mean and standard deviation. As a robustness check, we estimate models that exclude events with unusually large death tolls.

As water bodies are not confined to national boundaries, some floods in the archive (less than 10 percent) are regional in scope. For these events, the reported number of deaths is the aggregate figure per event, with no available split between the countries affected. Because of this restriction, our sample excludes multi-country floods from all models.

The DFO reports the magnitude of a flood as the log of the product of three terms: area affected by the flood (in km^2) × flood duration (in days) × 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. Flood magnitude varies much less than either the number of floods or the number of deaths, with the standard deviation being smaller than the mean.

3.2 Exposure: Population in flooded areas

Each entry in the DFO's register of major flood events has an associated GIS polygon representing the area affected by that event. The DFO uses news and governmental sources to determine this geographic area. Using GIS, we overlaid flood maps with population maps from the Gridded Population of the World v3 (CIESIN-CIAT 2005) to obtain estimates of the population exposed to each event. Population grid maps are available in 5-year intervals since 1990. We calibrated an exponential curve for the remaining years to complete the panel. We used the resulting variable in the flood fatality and magnitude models (equations (2)-(4)) instead of national population, which was used in the flood frequency model (equation (1)) as observations in the latter model were defined as country-years.

The resulting estimates of population exposure to a flood are more accurate than statistics based on country-level population statistics, which previous studies on natural disasters have used. In our sample, mean population density in areas affected by floods is 394.46 persons/km^2, while mean population density at the country level is 154.53 persons/km^2. This difference reflects the fact that people have tended to concentrate in flood plains for millenia. Increased populations in flood plains is one explanation for the observed growth in number of floods (Figure 1; Freeman et al. 2003; IPCC 2007a, Chapter 3).

3.3 Vulnerability: Socioeconomic and governance 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). Although GNI per capita more accurately measures the income of a country's population, it was available for slightly few countries and years than GDP per capita. The choice between GDP per capita and GNI per capita is inconsequential in our models: we estimated all the models using both measures, and results were virtually indistinguishable.

Additional socioeconomic controls included in model variants were drawn from the same source, including domestic credit to the private sector, expressed as a percentage of GDP. Data on the Gini coefficient were drawn from a more complete World Bank source (Milanovic, 2005).

The governance indicators come from the International Country Risk Guide (ICRG) of Political Risk Services (PRS 2010). The ICRG is a popular source of governance indicators used in cross-country studies. It includes indicators for corruption, bureaucratic quality, law and order, democratic accountability, government stability, ethnic tensions, and religious tensions. It offers broad country coverage, which reduces the risk of selection bias (Kaufmann et al. 1999; Johnston 2001), and is available for a relatively long time period (1984 to the present), which conveniently covers the entire period that the DFO data are available, unlike governance indicators from all other sources. Indicators in the ICRG database take values between 0 and 6 (except bureaucratic quality and government stability, which have maximum values of 4 and 12, respectively), with higher values denoting better governance. We converted each to a 0-10 scale. A detailed description of the indicators along with their correlation coefficients is given in Appendix Table A1.

The benchmark regression specification included an aggregate governance index formed by averaging all seven indicators. Many studies have averaged or, equivalently, summed governance indicators, with the rationale being that averaging reduces measurement error if the indicators pertain to similar underlying concepts of governance and have independent errors (Knack and Keefer 1995; Mauro 1995, 1997; Ferreira and Vincent 2010). We also included the indicators individually, with particular attention paid to three of them: corruption, democratic accountability, and ethnic tensions. Escaleras et al

(2007) and Keefer et al. (2010) find that earthquake fatalities increase with corruption, while Anbarci et al. (2005) and Kahn (2005) find that fatalities are associated with ethnic fragmentation. Wheeler (2010) uses a variable capturing democratic accountability and citizens' political freedoms as a measure of transparency in disaster reporting.

Table 4 shows that the coefficient of variation for the income variable used in our models was larger within countries than between countries. Although it was smaller within countries than between countries for the governance variable, it remained relatively large in samples that included all the countries or just developing countries. The country effects apparently risk eliminating too much of the variation needed to identify the effects of the income and governance variables only for governance in developed countries.

3.4 Other controls

A country's total land area (km^2), urban population percentage, and mean annual national precipitation come from WDI (2010). Latitude (in absolute value), mean elevation (meters above sea level), and proximity to coast (measured by the percentage of land area within 100 km of ice-free coast) come from Gallup et al. (1999). Data on total forest area (km^2), encompassing both natural forests and plantations, are available 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 and expressed forest area as a percentage of total land area. Descriptive statistics for these variables are presented in Table 3. Aside from urban population percentage and forest percentage, all are time-invariant and appear in the models only if we exclude the country effects.

The WDI provides data on mean national precipitation for just 2008. Due to this limitation, our FE regressions do not include precipitation, but we doubt this omission biases the results. Appendix Table A2 shows that time-invariant physical features of countries explain 73 percent of the variation in the 2008 precipitation data, which implies that country effects should do a good job of controlling for differences in mean precipitation between countries.

4. Econometric methods

The number of floods in a country-year in equation (1) and the number of deaths during a flood event in equations (2)-(3) are non-negative count variables. Our preferred estimator is a quasi-maximum likelihood fixed effects Poisson model with robust standard errors (Wooldridge 2002, pp. 674-6), with the year effects included as dummy variables. Aside from requiring the fixed effects to have a multiplicative effect on the conditional mean, this model places no restrictions on the conditional distribution of the dependent variable. It provides consistent estimates of model parameters and their standard errors even if the distribution is overdispersed (the variance exceeds the mean; in a Poisson distribution, they are equal),[6] includes a large number of zeros, or exhibits serial correlation. These are substantial advantages compared to the negative binomial regression model used in previous disaster studies (Anbarci et al. 2005, Kahn 2005, Kellenberg and Mobarak 2008, Keefer et al. 2010), which generalizes the Poisson by assuming that overdispersion is caused by an unobserved effect that follows a Gamma distribution. Moreover, the unconditional version of the fixed effects negative binomial model does not provide consistent estimates when the number of panels is much above 20 (we have 92-108 countries, depending on the specification), while the conditional version does not control

[6] We formally tested for overdispersion using the tests in Hilbe (2007, p.47) and Cameron and Trivedi (2009, p.575). Neither rejected the null that there is no significant overdispersion ($p = 0.29$ and 0.71, respectively).

for individual fixed effects unless a very specific set of assumptions are met (Hilbe 2007, pp. 205-7, Guimarães 2008).

A random effects Poisson model is also available, but Hausman tests rejected it in favor of the fixed effects model ($p < 0.001$). A fixed effects model is also preferred conceptually (Wooldridge 2002, pp. 250-1): our sample is not a random draw of countries or flood events, and the magnitude of the number of countries in it is not much larger than the magnitude of the time dimension (24 years). In any event, the parameter estimates in the random effects model turn out to be similar to those in the fixed effects model, which is not surprising. The random effects estimator weights within variation relatively more heavily than between variation as the time dimension lengthens, and our sample period is relatively long compared to typical microeconometric applications of random effects models.

The use of Poisson and other limited-dependent variable models has been challenged, as their marginal effects often differ little from the marginal effects of linear models applied to the same data, despite the fact that a nonlinear model might fit the conditional expectation function better (Angrist and Pischke 2009, p. 107). Nonlinearity is clearly present in our data. Box-Cox transforms for equations (1)-(3) yield values of the theta parameter closer to zero than to one, which indicates that the conditional expectation function is better described by a log-linear model, which is the conditional expectation function for a Poisson model, than a linear model.[7] Plots of observed values and residuals versus predicted values also indicated nonlinearity. To better understand the consequences of modeling nonlinearity directly through the fixed effects Poisson model, we also

[7] Given that the dependent variables in equations (1)-(3) include zeros, we added 1 to the dependent variables before running the Box-Cox transforms, and we included both the country and year effects as dummy variables.

estimated equations (1)-(3) using a linear fixed effects model. And to investigate the importance of accounting for unobserved country effects,we also estimated the equations using a regular Poisson model, although this model is strongly rejected in favor of the fixed effects model ($p < 0.001$).

Flood magnitude is a continuous variable, and so linear regression analysis techniques are fully appropriate for estimating equation (4). We estimated it using pooled as well as fixed-effects models,[8] with robust standard errors clustered at the country level. Hence, three estimators were used for models (1)-(3)—linear fixed effects, regular Poisson, and fixed effects Poisson—while just pooled OLS and linear fixed effects were used for model (4).

Two specification issues applied to all four equations. The first was whether to express GDP per capita in logarithmic form, which is a common transformation in the literature. We estimated the models with this transformation and without it, and we found that results were not very sensitive to it. We therefore adhered to the convention and used the log of GDP per capita.

The second issue was testing for nonlinear effects of income and governance. We estimated four versions of each equation/estimator combination: linear income with linear governance, linear income with quadratic governance, quadratic income with linear governance, and quadratic income with quadratic governance. We selected the quadratic specification as the preferred specification when the linear and squared terms were both individually significant at 10% or better.

[8] A significant likelihood-ratio test statistic (P-value=0.00) leads us to reject the pooled model, while a Hausman test (P-value=0.00) favored a fixed-effects over a random-effects model.

There could be a problem of sample selection with equations (2)-(3), because data on the number of deaths are only available for countries that experienced flooding episodes. This is sometimes called incidental truncation. We applied the test developed by Wooldridge (2002, p.667) for Poisson regression models and did not reject the null that there is no truncation bias.[9] This does not imply that there is no correlation between selection in a given period and the country effects or the explanatory variables, but it does rule out correlation between selection and the idiosyncratic errors.

5. Results

Tables 5-8 present estimation results for equations (1)-(4), respectively. All models shown exclude domestic credit, which was consistently insignificant and had a negligible effect on other coefficient estimates when it was included (results are available upon request).

5.1 Effects of income and governance

Choice of estimator has a large impact on the results. The first three columns of Tables 5-7 compare results across the linear FE, regular Poisson, and FE Poisson models for flood frequency (Table 5) and fatalities (Tables 6-7). We estimated four versions of each model according to the possible combinations of linear and quadratic income and governance but the tables present only the preferred specifications. The preferred specification is linear in income and quadratic in governance for both frequency and fatalities when the estimator is the FE Poisson model. The preferred specifications for fatalities are similar for the regular Poisson model, which implies that the time-invariant controls included in it (total area,

[9] This is a two-step method similar to Heckman's (1976) method for linear models. As in equation (1), in the selection equation, the probability of a flood is modeled as a function of socioeconomic and institutional variables (*Pop*, *Y*, *G*) and the natural characteristics of the country, **Z** (latitude, elevation, precipitation, coastal land, forested area, urban population). The test statistic 0.654 is smaller than 2.71, the 10 percent χ^2 critical value with $df = 1$.

elevation, latitude, coastal percentage, precipitation) capture the most important fixed differences between countries. In the flood frequency model, the preferred specification for the regular Poisson model includes both quadratic income and governance. Adding country effects to the Poisson model causes a loss of significance in the population, urban population percentage, and forest percentage variables. In contrast, a quadratic effect of governance does not appear in any of the preferred specifications for the linear FE models. We have more confidence in results from the FE Poisson model than results from the other two, as it is the only model that accounts for both unobserved heterogeneity across countries and the count-data nature of the dependent variables in the frequency and fatality models.

The first two columns of Table 8 similarly compare results for the pooled OLS and linear FE models for flood magnitude, which is a continuous variable. The preferred specifications again differ, with a quadratic effect of income detected in the linear FE model but not the pooled OLS model. We have more confidence in the results from the linear FE model, as it accounts for unobserved heterogeneity across countries.

Focusing then on the third column in Tables 5-7 and the second column in Table 8, the effect of income is negative and significant on frequency, fatalities conditional on magnitude, and magnitude up to a turning point of $4,120, which is at about the 50^{th} percentile of the sample and corresponds to countries at the lower end of the upper middle income group according to the World Bank's classification. These results imply that economic growth in low and lower middle income countries tends to reduce the frequency of floods, their magnitude, and, conditional on magnitude, the number of fatalities they cause. For countries in higher income groups (upper middle income, high income), economic growth provides two of the three benefits—reduced frequency and, conditional on magnitude, fatalities—but not reduced magnitude. In those countries, economic growth results in floods occurring less frequently but being larger when they do occur. The insignificant effect of income on fatalities in equation (2), which does not control for magnitude (Table 6, column 3), reflects these results: the negative effect of income on fatalities conditional on magnitude is offset by income's nonlinear effect on magnitude, which has a positive effect on fatalities (Table 7, column 3). So, at higher income levels, economic growth is associated with increased flood magnitude, which in turn is associated with increased fatalities.

Governance significantly affects flood frequency and fatalities but not magnitude. In the case of fatalities, it is significant both without and with the control for magnitude. Like the effect of income on magnitude, it has a U-shaped effect on frequency and fatalities, with turning points toward the interior of the distribution in the estimation sample. Improvements in governance thus tend to reduce the number of floods and fatalities in countries with weaker governance but to raise them in countries with stronger governance.

Splitting the sample between developing and developed countries reveals that the effect of governance on frequency and fatalities is due entirely to its effects in developing countries (columns 4-5 in Tables 5-7). For the developing country sample, the preferred specification for governance in the frequency and fatality models is the same as for the overall sample, i.e. quadratic (with some loss of significance for frequency), while governance does not have a significant effect, not even linearly, in any of the models for the developed country sample. This difference could be due to the within-country variation in the governance variable being greater in the former sample than the latter (Table 4); if so, we failed to identify an effect of governance on flood frequency and fatalities in developed countries purely for a statistical reason, not because no effect exists.

In contrast, the U-shaped effect of income on flood magnitude is due entirely to the influence of developed countries in the overall sample, as this effect is observed only in the developed country sample. A U-shaped income effect is also observed for both fatality models in the developed country sample. The turning points in all three cases are at the lower end of the distribution of income values in the sample, however, which indicates that, instead of being U-shaped, income actually has an increasingly positive impact on magnitude and fatalities in developed countries. It also has a significant positive effect, albeit a linear one, on flood frequency. So, economic growth tends to worsen all three aspects of flooding in developed countries. A beneficial effect of economic growth on flooding occurred only in developing countries, where it significantly reduced flood frequency and, conditional on flood magnitude, reduced fatalities in a marginally significant way.

Reverting to the all-country sample, the effects of income and governance on fatalities and magnitude are heavily influenced by high-fatality flood events, defined as ones in the 95th percentile (column 6 in Tables 6-7, column 5 in Table 8). Excluding those events causes governance to become insignificant in both fatality models (it was already insignificant in the magnitude model) and income to retain marginal significance only in the fatality model that controls for magnitude, with the effect being negative for most countries (the relationship is an inverted U, but the turning point is low). Income and governance evidently matter only for floods that pose the greatest risk to affected populations.

Appendix table A3, for flood frequency and magnitude, and table A4, for flood fatalities, show the results of the preferred specifications for corruption, ethnic tensions and democratic accountability, the individual indicators of governance previously analyzed in the literature. While the effects of corruption and ethnic tensions on fatalities and magnitude are similar to the effects of overall governance, democratic accountability is mostly insignificant.

5.2 Effects of other variables

Aside from income and governance, population of the affected area, urban population percentage, and forest area percentage are the only time-varying explanatory variables in the models discussed so far. Forest area percentage does not have a significant effect in any of the FE models. In the all-country sample (column 3 in Tables 5-7, column 2 in Table 8), the only significant effect of population or urban population percentage is a negative one on flood magnitude. These variables thus reduce the number of fatalities indirectly. A negative effect of population on magnitude also occurs in the developing country sample and is the only significant effect of population in that sample. In contrast, for developed countries a marginally significant, negative effect on magnitude occurs alongside positive effects on frequency and fatalities, especially fatalities conditional on magnitude. The effects of urban population percentage also differ between the two samples, being significant and positive for flood frequency, and significant and negative for magnitude, in the developing country sample but oppositely signed in the developed country sample.

The negative effects of population and urban population percentage on flood magnitude in the all-country sample persist when high-fatality floods are excluded (column 5 in Table 8). In addition, population now has a significant, positive effect in both fatality models, similar to its effect in the developed country sample.

The final columns of Tables 5-8 show results for models that include the Gini coefficient. Including this variable cuts the sample by more than half. Even without including the Gini (results not shown, but available upon request), models restricted to this sample show much less evidence of a significant effect of income or governance than corresponding models estimated using data from all countries or just developing or developed countries. So, the lack of significance of income and governance in the models in the final columns is due to a sample-selection effect, not the addition of the Gini. The notable result in these models is that the Gini has a positive and significant effect on fatalities (both without and with the control for magnitude) and magnitude. Increased inequality thus tends to increase fatalities both directly and indirectly.

6. Discussion and Conclusions

Some of our results are consistent with ones previously reported. The robust, positive impact of flood magnitude on the number of deaths echoes findings from studies on earthquakes (Kahn 2005, Anbarci et al. 2005, Keefer et al. 2010), as does the positive impact of inequality on fatalities (Anbarci et al. 2005). Previous studies report that larger national or regional populations are positively associated with fatalities from various types of natural disasters (Kahn 2005, Anbarci et a. 2005, Kellenberg and Mobarak 2008, Keefer et al. 2010), similar to our finding that, at least in developed countries, larger populations in affected areas are associated with increased flood fatalities, while an increased urban population share does not affect flood fatalities (Kellenberg and Mobarak 2008). The lack of a significant effect of forests is consistent with Van Dijk et al.'s (2009) argument that Bradshaw et al.'s (2007) finding of a significant effect was due to inadequate control for potentially confounding factors.

Our results for income and governance are strikingly different from previous papers, however. Most previous studies find income to decrease disaster mortality (Kahn 2005, Anbarci et al. 2005, Keefer et al. 2010), with Kahn (2005) finding it to decrease flood occurrence too. We find these beneficial effects of income only for developing countries, which contradicts Kellenberg and Mobarak's (2008) finding of an inverted-U relationship between income and flood mortality. Our results are the opposite for developed countries: increased income is associated with more fatalities, both directly (conditional on flood occurrence and magnitude) and indirectly through an increase in the frequency and magnitude of flood events.

There are several reasons why one might expect increased income to reduce disaster mortality. It can support development of better forecasting and warning systems, as investment in computer modelling of storms and early warning systems can facilitate mass evacuations and save lives (Sheets & Williams 2001). It can also facilitate the provision of better medical care, emergency treatment, and crisis management (Athey and Stern, 2002). In the case of floods, however, some other investments that larger incomes enable—specifically, infrastructural solutions to flood control—might be less benign. While some infrastructural solutions, in particular dams, can reduce the frequency and magnitude of flood events, channelization and levee construction can increase flood stages. There is little disagreement among hydrologists that levees increase flood levels. Floodplain encroachment and managed flood-control systems alter natural flooding patterns, which can increase the number of floods (Pinter 2005). For example, levee construction and channelization have deepened and narrowed the major rivers of North America. Narrower channels exhibit more variable and higher discharges than broader, unimpounded rivers. River engineering might thus magnify flood stages and shorten the average recurrence interval for major floods (Criss and Shock 2001). In the United States, this process has continued even after disastrous floods have occurred, such as the great Midwestern flood of 1993 (Pinter 2005). The positive effect of income on flood frequency and magnitude in developed countries perhaps reflects this river engineering approach, while the negative effect of income on flood frequency in developing countries reflects an approach that, so far anyway, has relied more on dams.

Despite resulting in more frequent and larger floods, river engineering may result in a "safe development paradox" (Burby 2006), with people believing that levees and other flood-control infrastructure will protect them and thus exposing themselves to higher risks and failing to take private actions to protect themselves. The large number of fatalities in New Orleans during Hurricane Katrina has been held up as a recent example of this (Burby 2006). This paradox could explain the positive effect of income on flood fatalities in developed countries, even controlling for flood occurrence and magnitude. In contrast, the negative income effect in developing countries could be due to increased investment in early warning systems, evacuation programs, and emergency medical care. Our results imply that there is still a gap between developing and developed countries in this regard, however: although flood magnitude has a positive impact on the number of deaths in both groups of countries, the size of its impact is slightly larger in developing countries, which is consistent with those countries having fewer resources to cope with larger floods.

The safe development paradox also offers a possible explanation for our finding that larger population exposure results in a larger number of deaths in developed countries but not in developing countries. Facing a flood, people in developed countries may be more likely to think they will be protected by levees, while people in developing countries may be more likely to evacuate. Population in the affected area has a very robust negative impact on flood magnitude across all samples, including both developing and developing countries, which suggests that the safe development paradox is not simply a matter of the number of people located in flood zones but also their behavior and the behavior of governments toward them. More people means more hands to fight a flood, and it also means a higher payoff to actions that mitigate flooding in heavily populated areas.

Differences between developing and developed countries also appear for the other population variable in our models, the urban population percentage. Increased urbanization is associated with more frequent, smaller floods in developing countries but less frequent, larger ones in developed countries. The urbanization variable is measured at the national level, not the area affected by a flood, and it potentially reflects the effects of both physical and social factors: increased urbanization increases runoff because urban surfaces are more impervious than undeveloped land, but it also increase incentives for governments to prevent floods in urban areas. Differences in its effects between the two groups of countries may be due to differences in the relative importance of these two factors. The result for developed countries is consistent with governments choosing to manage floods so as to spare cities, for example by flood diversion and inundation of large rural areas. This would be reflected in the DFO's flood magnitude measure, which includes the area affected as one of its three components.

Regarding governance, our results indicate that it helps explain flood mortality only in developing countries. In addition, they indicate that its effect is more complicated than suggested in previous papers, which have examined only a linear effect, with higher levels of democratic accountability and lower levels of corruption being associated with reduced disaster mortality (Kahn 2005, Keefer et al. 2010). We find that improvements in our governance index reduce flood frequency and flood mortality in developing countries only up to a point, which roughly corresponds to the mean/median. Beyond that threshold, further improvements in governance are associated with increases in both flood frequency and flood mortality. We find no effects of improvements in governance in developed countries, although that might be due to our governance index varying less within those countries than developing countries.

One possible explanation for the reversal of the effect of governance in developing countries is a combination of what has been called the "local government paradox" (Burby 2006) in the flood control and government disaster policy literature, and the emphasis on decentralization by institutional strengthening programs promoted by international development organizations. The local government paradox is the proposition that local governments take natural hazards less seriously than central governments do. Although elected officials at the national level may face distorted incentives to invest in disaster preparedness—Healy and Malhotra (2009) show that voters reward incumbents for delivering disaster relief but not for investing in disaster prevention—Burby (2006) argues that this distortion is more marked at the local level. In the U.S., there are examples of local officials resisting proposals to reduce storm risks because they did not want to pay their share of federal projects. Local governments care more about “tangible” benefits like creating employment, constructing new schools, etc. than protecting the population against risks that may not materialize.

Decentralization programs might have inadvertently made the local government paradox more prominent in developing countries. Decentralization has been at the center stage of institutional reform over the last thirty years in a large number of developing and transition economies. Independently of the direction of causality between decentralization and governance, our results are compatible with a process of institutional improvement associated with devolution of power from the central to local governments and the local government paradox. Beyond the turning point in the U-shaped governance relationship, this effect would dominate, and thereby increase flood frequency and mortality, over other positive impacts associated with improved governance. Anecdotal evidence from the aftermath of Hurricane Mitch supports this hypothesis:

> Hurricane Mitch has highlighted the abilities and limitations of municipalities and other local actors in Central America to act in the immediate aftermath of a disaster and in the period of reconstruction. Local actors have mobilized a remarkable effort following Mitch; however they were often forced to respond in an ad-hoc fashion due to the inadequacy of both disaster preparation and internal capacities, and the lack of financial resources. As a result, the Hurricane has also re-energized the debate on decentralization as a factor in the region's reconstruction and long term development.
>
> http://www.iadb.org/regions/re2/consultative_group/groups/decentralization_workshop.htm

In principle, we could test the potentially opposing effects of governance and decentralization by adding a variable that measures degree of decentralization to our models. Unfortunately, decentralization indicators for our sample are not readily available.

We do not believe that our results are driven by improved reporting of the number of floods and fatalities associated with larger incomes or better governance. If that were the case, we would expect income to have a positive (not a negative) impact on flood frequency in developing countries. Better reporting cannot satisfactorily explain the nonlinear impacts of governance either. Moreover, our regressions include country and time fixed effects. 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 might 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. Time fixed effects will pick them up as long as these improvements are driven by, say, technological change (e.g., improvements in remote sensing, which DFO uses extensively) or international initiatives that are common to all the countries.

The result that income and governance matter only when we include high-fatality floods parallels a finding that these variables have larger effects on earthquake fatalities when the sample is limited to large earthquakes (Keefer et al. 2010). It could be due to the aggregate nature of our measures of income and governance, which are measured at the national level. Big events that cause many fatalities are more likely to attract the attention of national governments than small events, which are more likely to be left to state and local governments to manage. If so, then it makes sense that our income and governance variables are significant when we include the larger events but not when we exclude them, as they do not reflect the differences in income and governance that exist between different parts of a country and are important for explaining subnational responses to smaller floods.

Identifying the effects of income and governance on smaller flood events might therefore require the development of more disaggregated versions of these variables, comparable to the event-specific population variable that we used in our flood fatality and magnitude models.

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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: Authors from 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: Effects of vulnerability indicators on flood mortality

	Indirect effects	**Direct effects**
	Through flood occurrence and magnitude	Conditional on flood occurrence and magnitude
Preemptive	Zoning regulations	Zoning/building regulations
	Infrastructure (e.g. dams)	Monitoring and information systems
Reactive	Infrastructure (e.g. dam release)	Emergency services
	Other (e.g. sandbags)	

Table 3: 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
Governance index	6.31	1.69	1.29	9.70
Corruption	4.90	2.13	0	10
Ethnic tensions	6.34	2.36	0	10
Democratic accountability	6.64	2.73	0	10
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 (%)	53.07	22.74	9.16	100
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

Data Sources: 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 (2010) for Governance indicators. Gallup et al. (1999) for physical characteristics. Flood magnitude = log(affected area*flood duration * flood severity). See text for detailed description of variables.

Table 4: Decomposition of coefficient of variation of key explanatory variables

	All sample			Developing countries			Developed countries		
Variable	Overall	Between	Within	Overall	Between	Within	Overall	Between	Within
ln(GDP pc PPP)	0.243	0.163	0.185	0.203	0.139	0.161	0.331	0.247	0.260
Governance	0.267	0.219	0.112	0.212	0.179	0.141	0.096	0.126	0.046
ln(Population)	0.213	0.133	0.191	0.211	0.121	0.190	0.216	0.149	0.191
Urban population (%)	0.430	0.422	0.070	0.438	0.451	0.093	0.118	0.230	0.025
Forest area (%)	0.582	0.664	0.088	0.626	0.714	0.103	0.448	0.524	0.028

Table 5. Results for equation (1), flood frequency. Dependent variable: no. floods per country-year; ln(no. floods+1) in linear FE model. Time-invariant controls in the regular Poisson model are ln(national area), mean national elevation and latitude, national annual average precipitation, and national coastal percentage.

Variables	Linear FE: linear Y&G	Poisson: quadratic Y&G	FE Poisson: quadratic G	FE Poisson: developing countries, quadratic G	FE Poisson: developed countries, linear Y&G	FE Poisson: Gini coefficient, linear Y&G
ln(GDP pc PPP)	0.0110	-0.775*	-0.518***	-0.726***	2.101**	0.103
	(0.0649)	(0.422)	(0.180)	(0.220)	(0.855)	(0.278)
ln(GDP pc PPP)^2		0.0544**				
		(0.0256)				
Governance	-0.0259	-0.304**	-0.460**	-0.530*	0.0324	-0.0389
	(0.0166)	(0.123)	(0.216)	(0.288)	(0.129)	(0.0583)
Governance^2		0.0224**	0.0376**	0.0430*		
		(0.0113)	(0.0183)	(0.0258)		
ln(National population)	0.112	0.566***	0.603	-0.0882	6.583***	1.327
	(0.229)	(0.0340)	(0.751)	(0.839)	(1.704)	(1.214)
Urban pop. (%)	0.00789	-0.00770***	0.0217	0.0383***	-0.213***	0.00112
	(0.00679)	(0.00257)	(0.0154)	(0.0142)	(0.0655)	(0.0211)
Forest area (%)	0.0822	-1.847***	0.157	0.790	0.456	-0.268
	(0.733)	(0.227)	(1.735)	(1.759)	(4.324)	(2.094)
Gini coefficient						-0.00834
						(0.0160)
Time-invariant controls	No	Yes	No	No	No	No
Country FE	Yes	No	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Turning point: Y	-	$1,240	-	-	-	-
Turning point: G	-	6.8	6.1	6.2	-	-
Observations	2,292	2,244	2,292	1,681	611	637
Countries	107		107	79	28	76

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 6. Results for equation (2), flood fatalities. Dependent variable: number of deaths per flood event in Poisson and FE poisson models; ln(no. deaths+1) in linear FE model. Time-invariant controls are the same as in Table 5.

Variables	Linear FE: linear Y&G	Poisson: quadratic G	FE Poisson: quadratic G	FE Poisson: developing countries, quadratic G	FE Poisson: developed countries, quadratic Y	FE Poisson: fatalities < 95th percentile, linear Y&G	FE Poisson: Gini, linear Y&G
ln(GDP pc PPP)	-0.467**	-0.716***	-1.317	-1.376	-71.32***	-0.0716	-1.862*
	(0.229)	(0.241)	(0.928)	(1.051)	(15.51)	(0.264)	(1.000)
ln(GDP pc PPP)^2					3.582***		
					(0.804)		
Governance	-0.0405	-1.576**	-2.792***	-2.970***	0.291	-0.0546	0.0890
	(0.0572)	(0.615)	(0.484)	(0.496)	(0.375)	(0.0641)	(0.155)
Governance^2		0.148**	0.260***	0.279***			
		(0.0627)	(0.0582)	(0.0599)			
ln(Affected population)	0.0622**	-0.254	-0.265	-0.297	0.0489*	0.0557**	0.0995
	(0.0240)	(0.252)	(0.332)	(0.358)	(0.0287)	(0.0239)	(0.0925)
Urban pop. (%)	0.00107	-0.00892	-0.0494	-0.0505	0.107	0.000118	0.0293
	(0.0174)	(0.00921)	(0.0433)	(0.0460)	(0.135)	(0.0273)	(0.0656)
Forest area (%)	-0.128	-0.609	1.441	2.042	-4.595	-0.150	-1.220
	(1.483)	(1.351)	(6.661)	(7.267)	(10.77)	(1.579)	(6.123)
Gini coefficient							0.0704**
							(0.0310)
Time-invariant controls	No	Yes	No	No	No	No	No
Country FE	Yes	No	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Turning point: Y	-	-	-	-	$21,064	-	-
Turning point: G	-	5.3	5.4	5.3	-	-	-
Observations	2,188	1,934	2,172	1,626	546	2,061	969
Countries	108		92	72	20	92	61

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 7. Results for equation (3), number of flood fatalities conditional on flood magnitude. See comments in Table 6.

Variables	Linear FE: quadratic Y	Poisson: quadratic G	FE Poisson: quadratic G	FE Poisson: developing countries, quadratic G	FE Poisson: developed countries, quadratic Y	FE Poisson: fatalities < 95th percentile, quadratic Y	FE Poisson: Gini coefficient, linear Y&G
Magnitude	0.468***	0.660***	0.734***	0.749***	0.716***	0.447***	0.586***
	(0.0463)	(0.161)	(0.162)	(0.176)	(0.0867)	(0.0299)	(0.127)
ln(GDP pc PPP)	1.763*	-1.463**	-1.241**	-1.229*	-44.64***	2.629*	-1.606**
	(0.926)	(0.598)	(0.573)	(0.639)	(13.51)	(1.490)	(0.658)
ln(GDP pc PPP)^2	-0.140**				2.249***	-0.173*	
	(0.0630)				(0.686)	(0.0982)	
Governance	-0.0393	-2.392***	-2.977***	-3.167***	0.160	-0.0615	0.111
	(0.0474)	(0.920)	(0.503)	(0.504)	(0.403)	(0.0531)	(0.113)
Governance^2		0.222**	0.276***	0.296***			
		(0.0869)	(0.0596)	(0.0607)			
ln(Affected population)	0.126***	-0.0513	-0.235	-0.267	0.155***	0.134***	0.227
	(0.0221)	(0.244)	(0.412)	(0.442)	(0.0526)	(0.0257)	(0.153)
Gini coefficient							0.0516*
							(0.0310)
Time-invariant controls	No	Yes	No	No	No	No	No
Country FE	Yes	No	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Turning point: Y	$543	-	-	-	$20,423	$1,995	-
Turning point: G	-	5.4	5.4	5.3	-	-	-
Observations	2,194	2,194	2,178	1,627	551	2,067	969
Countries	109	109	93	72	21	93	61

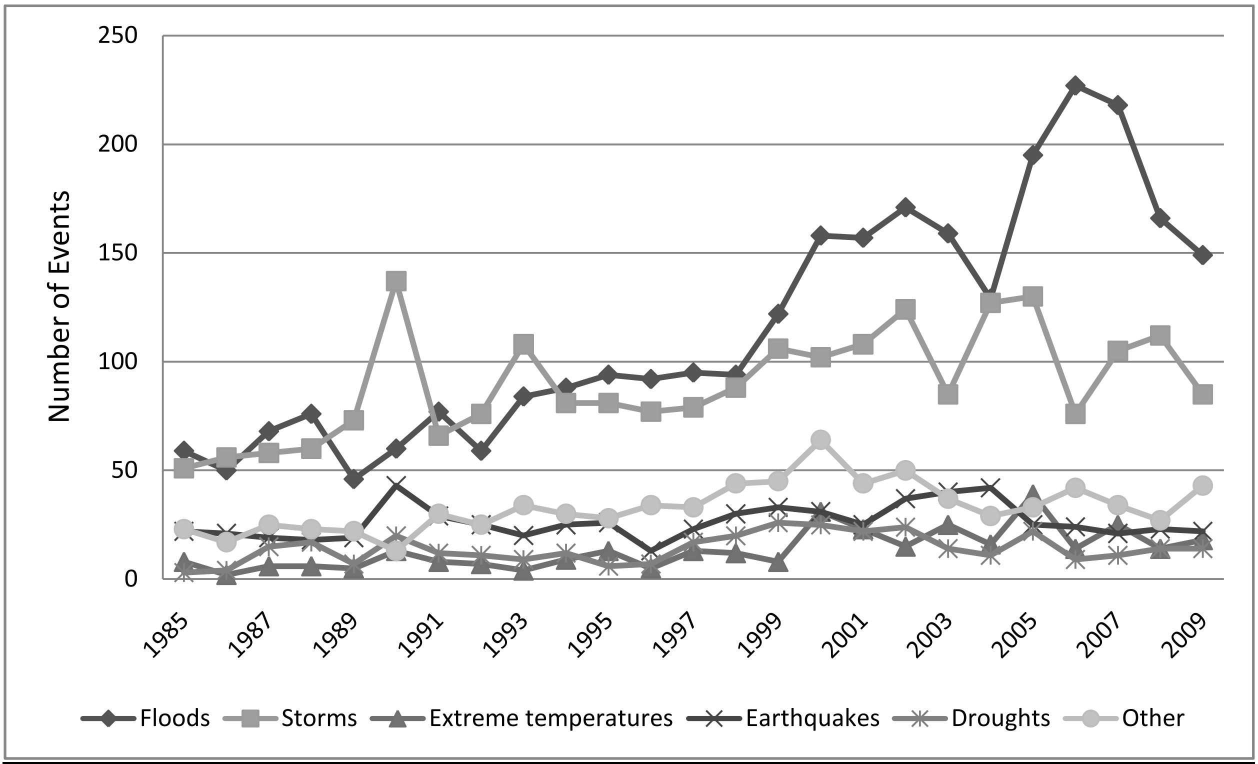
Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 8. Results for equation (4), flood magnitude. Dependent variable: physical magnitude of a flood event, expressed as ln(affected area × flood duration × flood severity); see text for details. Time-invariant controls: same as in previous tables.

Variables	Pooled OLS: linear Y&G	Linear FE: quadratic Y	Linear FE: developing countries, linear Y&G	Linear FE: developed countries, quadratic Y	Linear FE: fatalities < 95th percentile, linear Y&G	FE Poisson: Gini coefficient, linear Y&G
ln(GDP pc PPP)	-0.115	-2.264**	-0.105	-11.84**	-0.269	-0.351
	(0.0783)	(1.001)	(0.167)	(5.570)	(0.180)	(0.349)
ln(GDP pc PPP)^2		0.136**		0.597**		
		(0.0646)		(0.282)		
Governance	0.000327	-0.00219	0.0167	-0.0764	-0.0105	-0.143**
	(0.0371)	(0.0348)	(0.0302)	(0.131)	(0.0373)	(0.0645)
ln(Affected population)	-0.151***	-0.138***	-0.168***	-0.0968*	-0.140***	-0.170***
	(0.0279)	(0.0302)	(0.0297)	(0.0566)	(0.0304)	(0.0390)
Urban pop. (%)	-0.00299	-0.0296**	-0.0343***	0.116***	-0.0335**	-0.0442
	(0.00306)	(0.0127)	(0.0123)	(0.0298)	(0.0128)	(0.0289)
Forest area (%)	0.252	-0.156	-0.841	2.312	0.390	-1.482
	(0.253)	(0.988)	(0.989)	(2.526)	(1.005)	(1.871)
Gini coefficient						0.0296**
						(0.0139)
Time-invariant controls	Yes	No	No	No	No	No
Country FE	No	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Turning point: Y	-	$4,120	-	$20,257	-	-
Observations	1,934	2,188	1,634	554	2,077	984
Countries		108	80	28	108	76

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Figure 1: Incidence of natural disasters 1985-2009



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

Appendix

Table A1: Governance Indicators

Panel A — **Definitions of governance indicators**

Indicator	Excerpt from variable descriptions in ICRG at www.prsgroup.com
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."
Bureaucratic Quality	"the bureaucracy has the strength and expertise to govern without drastic changes in policy or interruptions in government services"
Law and Order	"assessment of the strength and impartiality of the legal system" and "of popular observance of the law"
Ethnic Tensions	"the degree of tension within a country attributable to racial, nationality, or language divisions"
Religious Tensions	"the risk involved in these situations range from inexperienced people imposing inappropriate policies through civil dissent to civil war"
Government Stability	"government's ability to carry out its declared program(s), and its ability to stay in office"
Democratic Accountability	"how responsive government is to its people, on the basis that the less responsive it is, the more likely it is that the government will fall, peacefully in a democratic society, but possibly violently in a non-democratic one"

Panel B — **Correlation coefficients among governance indicators**

	Corruption	Bureaucratic Quality	Law and Order	Ethnic tensions	Religious tensions	Government Stability	Democratic Accountability
Corruption	1	0.6738	0.6025	0.3958	0.4899	0.0406	0.5520
Bureaucratic Quality		1	0.6495	0.3895	0.3111	0.2626	0.5961
Law and Order			1	0.5500	0.4617	0.4434	0.3250
Ethnic tensions				1	0.5477	0.3453	0.1071
Religious tensions					1	0.2057	0.1730
Government Stability						1	-0.0302
Democratic Accountability							1

Source: International Country Risk Guide (ICRG) at www.prsgroup.com

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

Table A3: Individual governance indicators: results for equation (1), flood frequency, and equation (4), flood magnitude

	Eq (1): Flood frequency FE Poison: quadratic G				**Eq (3): Flood magnitude** Linear FE: quadratic Y			
VARIABLES	Governance	Corruption	Ethnic tensions	Democratic accountability	Governance	Corruption	Ethnic tensions	Democratic accountability
Ln(GDP pc PPP)	-0.518***	-0.519***	-0.469**	-0.585***	-2.264**	-2.260**	-2.333**	-2.305**
	(0.180)	(0.198)	(0.195)	(0.215)	(1.001)	(1.054)	(1.082)	(1.024)
Ln(GDP pc PPP)^2					0.136**	0.136**	0.140**	0.138**
					(0.0646)	(0.0674)	(0.0691)	(0.0655)
Governance	-0.460**				-0.00219			
	(0.216)				(0.0348)			
Governance^2	0.0376**							
	(0.0183)							
Corruption		0.0207				0.00711		
		(0.107)				(0.0157)		
Corruption^2		-0.00563						
		(0.00950)						
Ethnic			-0.0242				0.00773	
			(0.0752)				(0.0210)	
Ethnic^2			-0.00212					
			(0.00672)					
Accountability				-0.0456				-0.0123
				(0.0730)				(0.0186)
Accountability^2				0.00198				
				(0.00568)				
Ln(population)	0.603	0.599	0.668	0.462	-0.138***	-0.139***	-0.138***	-0.138***
	(0.751)	(0.826)	(0.777)	(0.809)	(0.0302)	(0.0301)	(0.0301)	(0.0302)
Urban pop. (%)	0.0217	0.0199	0.0245	0.0183	-0.0296**	-0.0295**	-0.0298**	-0.0315**
	(0.0154)	(0.0165)	(0.0154)	(0.0173)	(0.0127)	(0.0126)	(0.0125)	(0.0137)
Forest area (%)	0.157	0.530	0.809	0.336	-0.156	-0.0679	-0.120	-0.425
	(1.735)	(1.724)	(1.549)	(1.685)	(0.988)	(1.005)	(0.991)	(1.075)
Turning point: Y	-	-	-	-	$4,120	$4,060	$4,155	$4,236
Turning point: G	6.1	-	-	-	-	-	-	-
Observations	2292	2292	2292	2292	2188	2188	2188	2188
Countries	107	107	107	107	108	108	108	108

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A4: Individual governance indicators: results for equation (2), flood fatalities, and equation (3), flood fatalities conditional on magnitude

	Eq (2): Flood fatalities FE Poisson: quadratic G				**Eq (3): Flood fatalities conditional on magnitude** FE Poisson: quadratic G			
VARIABLES	Governance	Corruption	Ethnic tensions	Democratic accountability	Governance	Corruption	Ethnic tensions	Democratic accountability
Magnitude					0.734***	0.677***	0.759***	0.709***
					(0.162)	(0.179)	(0.184)	(0.173)
Ln(GDP pc PPP)	-1.317	-0.615	0.133	-0.591	-1.241**	-0.411	-0.438	-0.902
	(0.928)	(0.803)	(0.572)	(0.799)	(0.573)	(0.631)	(0.504)	(0.860)
Ln(GDP pc PPP)^2								
Governance	-2.792***				-2.977***			
	(0.484)				(0.503)			
Governance^2	0.260***				0.276***			
	(0.0582)				(0.0596)			
Corruption		-1.096***				-1.087***		
		(0.273)				(0.308)		
Corruption^2		0.125***				0.122***		
		(0.0414)				(0.0463)		
Ethnic			-1.113***				-1.086***	
			(0.340)				(0.387)	
Ethnic^2			0.0686**				0.0607	
			(0.0312)				(0.0377)	
Accountability				-0.567				-0.643
				(0.393)				(0.414)
Accountability^2				0.0405				0.0496
				(0.0300)				(0.0321)
Ln(population)	-0.265	-0.269	-0.279	-0.268	-0.235	-0.238	-0.242	-0.236
	(0.332)	(0.344)	(0.335)	(0.330)	(0.412)	(0.429)	(0.404)	(0.407)
Urban pop. (%)	-0.0494	-0.0549	-0.139	-0.0984*				
	(0.0433)	(0.0537)	(0.0911)	(0.0535)				
Forest area (%)	1.441	0.446	-5.233	-4.260				
	(6.661)	(6.527)	(5.071)	(5.467)				
Turning point	5.4	4.4	8.1	-	5.4	4.5	-	-
Observations	2172	2172	2172	2172	2178	2178	2178	2178
Countries	92	92	92	92	93	93	93	93

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<