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Does rising income increase or decrease damage risk from natural disasters?

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Abstract

Recent empirical literature has found a negative relationship between income per capita and measures of risk from natural disaster, supportive of logic that higher incomes allow countries to mitigate disaster risk. We argue that behavioral changes at the micro level in response to increasing income (such as location choice and extent of costly abatement activity) may lead to a non-linear relationship between aggregate incomes and disaster damages, where the risks increase with income before they decrease. In a country-year panel data set, we show that disaster risk associated with flooding, landslides and windstorms increases with income up to GDP per capita levels of $5044, $3360, and $4688 per year respectively and decrease thereafter. Such non-linear impacts are absent for other disaster types such as extreme temperature events and earthquakes where the links between human behavioral choices and exposure to risk are not as strong. From a policy perspective, this suggests that for the least developed countries, the dual goals of disaster risk prevention and economic development cannot be assumed to be complementary for all forms of natural disaster. In addition to allocating resources to manage disaster risk, the poorest nations may have to be more proactive in enacting policies that alter the behavioral choices of citizens that impact a country's exposure to natural disaster risk.

JEL classification: O1; O2; D1; Q54; R5

Keywords: Economic development; Natural disaster; Kuznets curve; Urbanization

1. Introduction

The string of large natural disasters worldwide in the last few years, including the tsunami of 2004 that devastated coastal regions of Southeast Asia, earthquakes in South Asia, and hurricanes in the coastal United States and the Caribbean serve as shocking reminders of the tremendous power of nature to effect deaths and damages in both developed and developing countries alike. Many scholars have argued that the social and economic costs of natural disasters are disproportionately borne by poor people in developing countries. Kahn (2005) points out, for example, that between 1980 and 1999, India experienced fourteen earthquakes that killed a total of 12,137 people while the United States experienced nine earthquakes that killed only 137 people. Worldwide, natural disasters killed an estimated 2.69 million people and led to US $955 billion in economic

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damages between 1970 and 2001 (Yang, 2005), but on a per capita basis, the losses were 20 times larger in developing countries than in industrialized nations (Bendimerad, 2000).

A seeming consensus has emerged in the literature that the risk of death and damages from natural disasters is monotonically decreasing in income. The logic that economic development allows a country to better manage and mitigate the risk from disasters has intuitive appeal, and recent empirical research using cross-sectional or panel macro data (e.g. UNDP, 2004; Anbarci et al., 2005; Kahn, 2005; Toya and Skidmore, 2007) report results that are broadly supportive of this logic. Adopting this view also lends itself to a simple and attractive macro-level policy prescription to manage the human and economic risk from natural disasters: allow countries to develop, and the risk of disaster damages should fall. Indeed, some policy analysts have argued that the best way to avoid large disaster damages is for poor countries to develop and grow faster (e.g. Okonski, 2004; Hoke, 2005).

The purpose of this paper is to challenge this emerging consensus in both academic and policy circles on the monotonic negative relationship between development and disaster damages. We present two related bits of evidence that argue in favor of a non-monotonic Kuznets inverted-U type relationship between development and disaster damages.

First, we argue based on simple behavioral analysis of risk-averse individuals that it is reasonable to expect that at low income levels, people may make choices such that disaster damages will increase with income, and that the overall relationship between disaster damages and income may be non-monotonic. For example, if higher levels of production generate greater disaster risk as a by-product, and if people can choose to forego consumption in order to mitigate that risk, it is entirely possible that this risk-return trade-off may swing in favor of consumption at low levels of income where the marginal utility of consumption is high, but then swing towards mitigation as income increases.

Second, we show empirical evidence of such non-linearities in a panel data set of disaster events, damages, and economic development covering 133 developed and developing nations, spanning 28 years. We first run the linear specifications akin to the current literature and are able to replicate the negative relationship between development and disaster damages that is reported in this literature, but then show that in richer models, there is evidence of more complicated non-linear impacts of development on the risk of deaths from disasters. These inverted-U non-linearities[1] appear to be stronger for floods, landslides, and windstorms than for extreme temperature events or earthquakes. The damage risks for floods, landslides, and windstorms have stronger links to abatement activity choice (e.g. building embankments) and habitation choice (e.g. locating close to coastal regions), which are the underlying mechanisms for the inverted-U relationships discussed in the theoretical analysis. It is more difficult for individuals to alter their risk of exposure to say, extreme temperatures through their behavioral choices.

These results suggest that poor countries may have to be more proactive in enacting policies that alter the behavioral choices of citizens that can potentially impact a country's exposure to natural disaster risk. As a simple example, a poor household in a developing country may find it in their interest to migrate to densely populated urban and peri-urban areas in search of better employment opportunities, even if that relocation is associated with increased exposure to disaster risk. In other words, disaster risk exposure may increase mechanically with rising income in low income countries, partly due to the dynamics of urbanization and development. The downturn in disaster damages that we observe in our data as that country continues to get richer may have to do with either the emergence of better institutions and technology in richer countries (e.g. better building codes and better construction of dwellings in the urban/peri-urban areas which lowers disaster damage risk) or to do with the fact that a richer person may not make that same risk-return trade-off in their relocation choice to urban areas (since the demand for safety likely increases with income). Before these positive forces of development kick in, a developing country concerned about disaster risk may have to be more proactive in controlling the rate or specific form of urbanization and in enacting other laws (e.g. zoning rules or building codes) that limit its citizens' exposure to natural disasters.

The next section conducts some graphical analysis of the raw data on disaster damages and income levels to show some basic evidence of the non-linear relationship in the absence of any control variables. Section 3 discusses potential links between development and disaster damages, and outlines a conceptual framework that can lead to a inverted-U shaped relationship between

[1] The inverted-U shape of the relationship between GDP per capita and the risk of death is akin to the shape postulated for economic development and income inequality (Kuznets, 1955; Jha, 1996, or List and Gallet, 1999), and also to that postulated for economic development and environmental quality (Grossman and Krueger, 1995; Hettige et al., 2000; Dasgupta et al., 2002; Millimet et al., 2003).

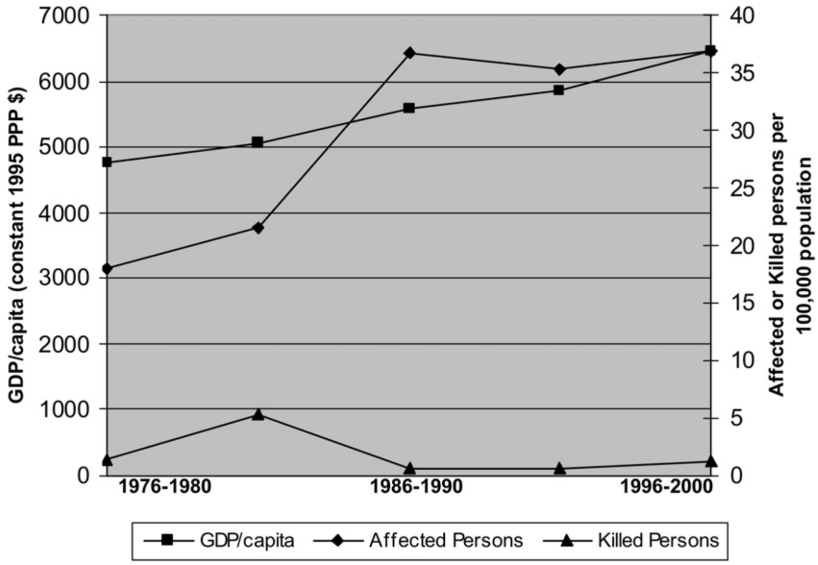


Fig. 1. World GDP/capita and # of people affected and killed by natural disaster/capita from 1976 to 2000.

these two variables. Section 4 presents the data set and our approach to the empirical estimation. The empirical results are discussed in Section 5 and Section 6 concludes.

2. The raw data on economic development and natural disaster risk

Much of the literature on the economics of natural disasters has focused on the economic impacts of disasters (Freeman et al., 2003; Skidmore, 2001; Skidmore and Toya, 2002; Austin and Romm, 2004; Hallstrom and Smith, 2005; Sadowski and Sutter, 2005), and insurance responses to disaster risk (Brookshire et al., 1985; Kunreuther, 1996; Cossette et al., 2003; Cummins et al., 2004). Our paper is most closely related to the literature on the reverse question: how a country's level of development affects its vulnerability to natural disasters (Adger, 1999; UNDP, 2004; Kahn, 2005; Anbarci et al., 2005).

Based on a cross-sectional sample of countries, UNDP (2004) reports that measures of economic development (GDP per capita and the Human Development Index) have negative correlations with deaths caused by natural disaster events in a country. Likewise, Anbarci et al. (2005) find a negative correlation between GDP per capita and earthquake fatalities. Kahn (2005) also concludes that there exists a negative relationship between GDP per capita and deaths from natural disasters. This evidence suggests that the simultaneous goals of poverty elimination and the reduction of natural disaster risk are complementary. The result, while generally correct for a large number of countries, masks the potential danger that at very low levels of income, economic development may increase natural disaster risk by changing micro behavior in such a way so as to increase aggregate exposure to disasters.

The presumption that as countries develop they are simply better prepared to deal with disasters, thereby reducing the number of people affected by disasters is generally not supported in the raw data. Figure 1 shows that although worldwide per capita income increased from $4705 in the late seventies to $6306 in the late nineties, the number of people affected by disasters per thousand doubled from 18 to 36 over the same time period. Likewise, the number of people killed per thousand increased from 0.68 during the 1986–1990 period to 1.38 during the 1996–2000 period. That is, more people are now affected by natural disasters worldwide *despite* rising world income.

Figure 2 examines the country level variation in damages by plotting the average number of people killed or affected per thousand in the population against GDP/capita for the 133 countries for which data is available.[2] Fitting a linear trend line reveals a negative relationship between disaster risk and economic development, which is the basic result pointed out by Kahn, 2005 and others. Note that the vast majority of the coun-

[2] GDP/capita is measured in constant 1995 PPP $, and averages for each country are over the 1975–2002 time period. A list of countries is provided in Appendix Table 1.

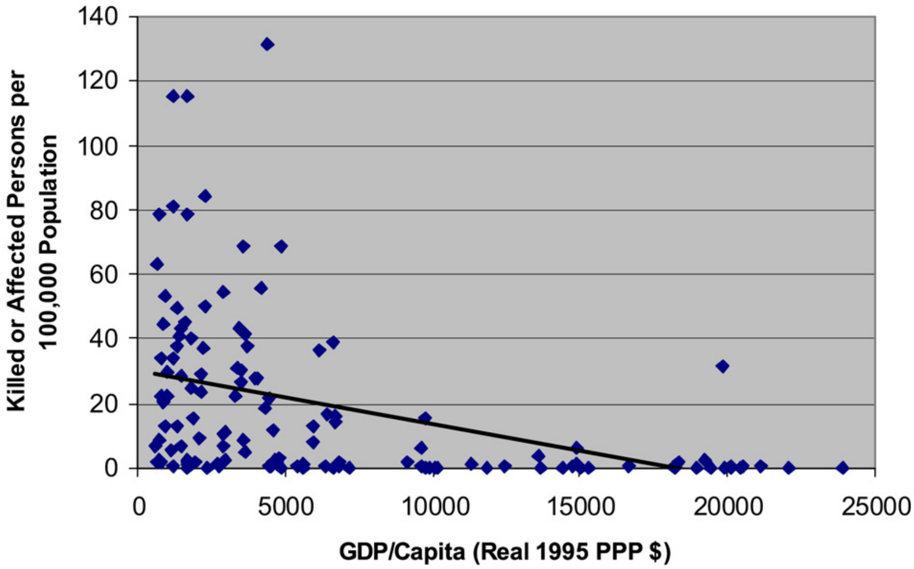


Fig. 2. Relationship between the average number of people killed or affected by disaster and average GDP/capita (1975–2002) for 133 countries.

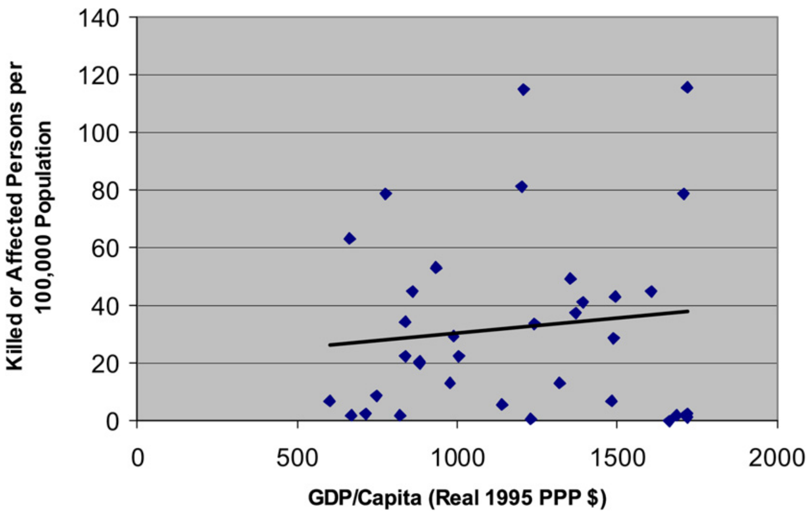


Fig. 3. Relationship between the number of people killed or affected by disaster and average GDP/capita (1975–2002) for countries with less than $1800/person/year.

try observations (99 out of 133) fall under a GDP per capita of $10,000 per year and that these countries have the highest average number of people killed or affected by disaster per capita.

To explore whether the negative trend line is being driven by high income, low disaster risk countries (such as Norway, Luxembourg, Switzerland, etc.), we break the sample of countries with less than $10,000 per person per year out and divide them into two subgroups: the 35 countries with GDP/capita of less than $1800 in Fig. 3, and the 64 countries with GDP per capita of between $1800 and $10,000 in Fig. 4. Fitting linear trend lines to the sub-samples convey a different story. Countries with GDP/capita less than $1800 experience greater natural disaster risk as they grow, while countries with GDP/capita greater than $1800 see a decline in natural disaster risk as income rises. These patterns are consistent with Skidmore and Toya (2002) finding that in regressions of disaster risk on income, the coefficient on income is smaller in absolute value in developing countries than in OECD economies.

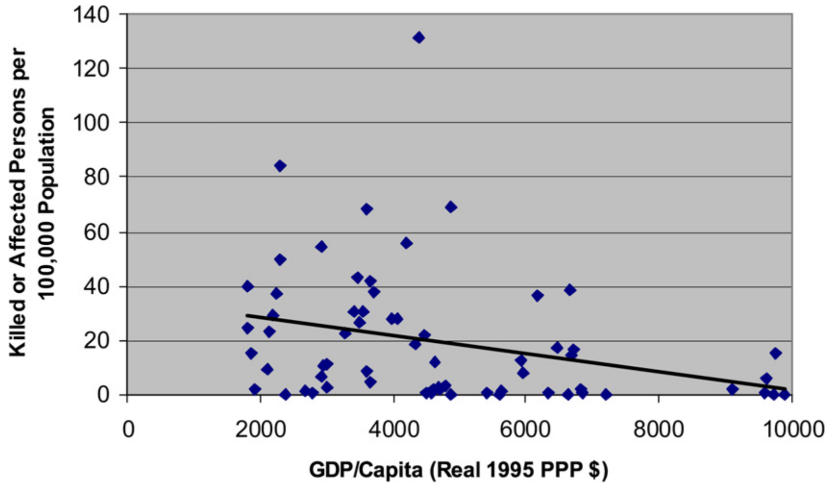


Fig. 4. Relationship between the number of people killed or affected by disaster and average GDP/capita (1975–2002) for countries with greater than $1800 but less than $10,000/person/year.

3. Conceptual links between development and natural disaster risk

3.1. Multiple competing influences of development on disaster risk

Based on the figures above, it appears that the underlying structural relationship between the level of development and natural disaster risk is probably a lot more complicated than simply the improved ability to mitigate risk that increased income can buy. Many factors correlated with development may have both positive and negative impacts on exposure to disaster risk. Urbanization is highly correlated with income per capita,[3] and can have a multitude of competing effects on natural disaster risk. In metropolitan areas, disaster risk may be mitigated by larger numbers of people having access to more adequate economic and social institutions, well designed infrastructure, and competent urban planning not found in more rural locations. On the other hand, in less developed countries where migration to urban centers overwhelms a city's capacity to deliver essential public services such as sanitation or clean drinking water to all of its citizens, or leads to inadequate housing and congestion, the number of people exposed to a natural disaster event may actually increase.

On the positive side, development may lower disaster risk exposure by raising the quality of institutions, education, or access to health-care. Transparent and competent government institutions that have disaster response plans in place are more likely to be capable of responding to natural disaster events than corrupt or disorganized governmental organizations who are only concerned about certain groups in society. For example, earthquakes in Turkey in 1999 (Özerdem, 2003) and in Algiers in 2003 (UNDP, 2004) caused large numbers of deaths due to poorly designed and enforced construction standards for private residential buildings. Educated populations are more capable of disseminating information and relaying risk prevention measures, while countries with greater access to quality health care will be better equipped to deal with the primary injuries associated with a disaster, as well as the potential secondary effects of famine and disease (UNDP, 2004).

Economic development can also have significant impacts on environmental quality and subsequent risks of natural disaster. For example, some ecologists claim that the destruction of mangrove forests along the Indonesian coast for shrimp farming and tourism, which raised standards of living and commerce, may have contributed to the destructive power of the 2004 tsunami, as the mangrove forests provide a natural barrier to buffer the force of waves (MSNBC, 2005). In some South and Central American countries, where the pressure to develop agricultural land has lead to the destruction of forests, larger populations of people have become more exposed to flood and landslide risk (UNDP, 2004).

[3] In the data set used for this paper, GDP per capita exhibits a positive correlation with the percentage of the population living in an urban area of 0.79.

3.2. Non-linearities in the effect of development on disaster risk

The aim of this paper is not to test these precise structural links between economic development and disaster risk, since identifying the effect of each of these channels separately would be an extremely difficult task within the confines of a cross-country data set. Instead this paper will simply argue that individuals' abatement and location choices can introduce non-linearities in the relationship between development and disaster risk, and that there is evidence of such non-linearities in the estimated reduced form relationship between per capita income and disaster deaths using cross-country panel data.

In this section we outline a framework that can generate an inverted-U relationship between development and natural disaster risk. The arguments presented are adapted from the utility theoretic model of a small closed economy with risk averse agents developed in Copeland and Taylor (2003), which they use to explain an inverted-U relationship between pollution levels and economic development.

Imagine an economy populated by consumers who receive positive but diminishing utility from increased consumption of goods, and receive disutility from increased risk of facing damages from natural disasters. Some by-products of the production technology, such as the depletion of environmental goods or urban congestion and pollution, can increase disaster risk. This assumption is motivated by some specific examples of mechanisms by which such by-products may increase the exposure to disaster risk noted in UNDP (2004), including

(a) pollution which contributes to global warming,
(b) sewage that raises the risk of contaminated drinking water,
(c) increased urban congestion that exacerbates disaster exposure and stifles emergency response times, or
(d) the loss of an environmental amenity (such as mangrove forests) that would have decreased the risk of disaster.

Thus, there is a trade-off embodied in the process of economic growth: the country gets richer with increased production, but the risk of natural disasters rises in the process.

Citizens can choose to devote some fraction of output to the abatement or containment of the negative impacts of production. For example, resources may be used for pollution control equipment, public goods like sewage treatment facilities or urban infrastructure, or wetland and forest reclamation. The amount of resources to divert towards such mitigating activities is a choice that consumers have to make. The cost of this choice is the foregone consumption from allocating greater resources to disaster mitigation, while the benefit is the disutility avoided by lowering disaster risk exposure.

The heart of our argument, which is based on intuition borrowed from the formal results derived in Copeland and Taylor (2003), is that consumers may very well arrive at different decisions on how much income to trade off to mitigate disaster risk depending on their baseline level of consumption. Given risk averse individuals whose marginal utility of income varies with the level of income, it is entirely possible that for consumers below some threshold consumption level, the marginal benefit of rising income is greater than the marginal damage associated with increased natural disaster risk. Thus disaster risk will rise along with income level in the lower part of the income distribution. Above that consumption threshold, the same citizen may choose to spend the marginal dollar of income on disaster mitigation, and at this point, disaster risk would drop with rising income levels.[4]

If the arguments above are correct, we would see disaster damages increasing with income levels in a sample of very poor countries, but the slope of this relationship would reverse in a sample of richer countries. These conceptual arguments are thus consistent with the raw data presented in Figs. 3 and 4. In the next section, we analyze more systematically whether such non-linear patterns emerge in cross-country panel regressions of the determinants of particular disaster types. We look for the impact of GDP changes on disaster damages controlling for the number of disaster events, so that the empirical tests correspond to the theoretical arguments presented here (in that we presume that the *extent* of damages holding fixed the number of disasters is determined by human choices). We control for country fixed effects, so that the source of identification is within-country changes in disaster damages as that country's income grows. Finally, we look at the relationship separately by disaster type, since some types of disaster

[4] While we highlight the choice of abatement activity as the micro behavior that can lead to non-linearities in the relationship between income levels and disaster damages, it is worthwhile to note that other human decisions such as location choice and urbanization in response to rising income opportunities in the urban area are other possible sources of a complicated relationship between income and disaster risk exposure.

damage are more responsive to human choices (e.g. floods) than others (e.g. extreme temperature events).

4. An empirical model of natural disaster risk

We estimate empirical models that explain the number of people killed by a natural disaster event in country i at time t, R_{it}, as a function of the number of people at risk (POP_{it}), a natural hazard damage function ($H(G_t, E_i)$), a function of income (I_{it}) and urbanization (Urb_{it}) that affects disaster risk ($B(I_{it}, Urb_{it})$),[5] the frequency of certain types of disaster events (f_{it}), and an error term (ε_{it}).

The natural hazard damage function is broken into two components. The variable G_t represents unobserved global environmental conditions that are common to all countries but are changing over time. Examples of such factors include the melting of polar ice caps, changes in ocean currents, or general global warming that affect the pattern of disaster occurrence worldwide. The second variable, E_i, is the geography or physical exposure component. It captures a country's exposure risk to certain types of natural disasters that may be a function of local landscape, geography, or historical events that are country specific and do not change over time (e.g. some island nations' vulnerability to cyclones or Iran or Peru's vulnerability to earthquakes). The relationship between disaster deaths and its components is expressed as:

$$R_{it} = r\big[POP_{it}, H(G_t, E_i), B(I_{it}, Urb_{it}), f_{it}, \varepsilon_{it}\big]. \tag{1}$$

We will model the natural hazard damage component of risk using a full set of year and country fixed effects. This represents an important departure from Kahn (2005) and Anbarci et al. (2005), who use region rather than country specific dummy variables. Both papers find that geography variables are significant in determining the number of people killed by natural disaster events. The goal of this paper is not to replicate their findings on geography variables, but to more fully explore the relationship between income and natural disaster risk, while adding in more precise controls for geographic differences. Country specific effects would also control for other unobserved, time-invariant characteristics of individual countries that may be correlated with total damage from disasters, including historical influences, institutional regime or other fixed cultural factors.

The conceptual analysis in the previous section highlights the possibility that natural disaster risk is also a function of vulnerabilities created during the process of development $B(.)$, which, in keeping with Copeland and Taylor (2003), we will model here as a function of a country's level of income, I_{it}, and also its degree of urbanization, since urban and rural areas typically face very different disaster risks. We will allow for the possibility that rising incomes can have both positive and negative effects on disaster risk in a country, and that countries at similar income levels, but with different levels of urbanization, may face different risks.

The fourth component of Eq. (1) accounts for the frequency of disaster events (f_{it}). All else equal, countries that experience more frequent natural disasters should expect a higher risk of death. An error term captures the inherent randomness of disaster deaths that remains even after time invariant country specific geographical effects, geographically invariant global effects, income levels, and the frequency of disaster events are all accounted for.

The base model for estimating the relationship between development and natural disaster risk is a linearized representation of (1), given as[6]

$$\ln R_{it} = \alpha_1 E_i + \alpha_2 G_t + \beta_1 POP_{it} + \beta_2 f_{it} + B(I_{it}, Urb_{it}) + \varepsilon_{it}. \tag{2}$$

Equation (2) is initially estimated with $B(I_{it}, Urb_{it})$ taking the two following functional forms:

$$B(I_{it}, Urb_{it}) = B(I_{it}, \cdot) = \beta_3 \ln I_{it}, \tag{2a}$$

and

$$B(I_{it}, Urb_{it}) = \beta_3 \ln I_{it} + \beta_4 (\ln I_{it})^2 + \beta_5 Urb_{it} + \beta_6 (\ln I_{it} * Urb_{it}). \tag{2b}$$

The International Disaster Database OFDA/CRED (2004) provides data on the frequency of disaster events and numbers of persons affected, and we obtain information on population, GDP per capita, and urbanization rates from the World Development Indicators (2004).

5. Estimation results

We use two different estimation methods. We first estimate a GLS log-linear specification similar to the strategy employed in UNDP (2004) and Kahn (2005).

[5] Here I is defined as GDP per capita and Urb is the percentage of the population living in an urban area.

[6] Following Kahn (2005), in the models estimated, we actually use $\ln(R_{it} + 1)$ as the dependent variable in order to avoid loss of observations due to the large number of zeros.

As an alternative, we also estimate using a negative binomial specification like that estimated in Anbarci et al. (2005). Given the count data nature of the dependent variable (a count of the number of people killed) and the fact that a large number of the observations are zero or very small, the transformed log-linear approach may not produce consistent estimates. The negative binomial model is chosen over the Poisson model due to the degree of over-dispersion in the data.[7]

We estimate the model on five different types of disaster events, as well as on total disasters where deaths from the five types are aggregated. The five types of disaster events are Floods, Earthquakes, Landslides, Windstorms, and Extreme Temperature Events. Table 1 presents the GLS and Negative Binomial estimation results for Eqs. (1) and (2a) on each of the disaster types *without* any controls for country or time specific effects. In-line with prior literature, we find that disaster deaths are decreasing in the level of development and increasing in population and the frequency of disaster events.[8]

In Table 2, we add controls for country and year specific effects. Country fixed factors such as proximity to shipping ports, mountainous versus flat landscapes, wet or dry climates, distance to equator, etc. may be correlated with both disaster damages and GDP per capita.[9] We add year dummies since technological advances between 1975 and 2002 have also systematically improved the capability of countries to keep track of and report on people affected by disasters. Once country and year fixed effects are added in Table 2, the negative relationship between income and disaster deaths is not as robust as previous estimates would suggest. In fact, for a number of specifications, income has a positive and significant effect on disaster deaths. This change in the direction of the effect of GDP per capita would be consistent with the claim that richer countries are endowed with better institutions to handle natural disaster damage, and the effects of such institutions are now being picked up by the country fixed effects (to the extent that the quality of those institutions are time invariant).

In Table 3 we estimate Eqs. (1) with (2b) to explore non-linearities in the relationship between income and natural disaster deaths, while controlling for time and country fixed effects. We report only negative binomial specifications in this table. The addition of the squared GDP/capita term reveals that the effect of income on deaths from natural disaster varies by disaster type. The behavior of Deaths from floods is highly non-linear, and follows an inverted-U shaped pattern with respect to GDP per capita. Our estimates indicate a turning point of approximately \$5600, which implies that flood deaths increase in income for countries with a per capita income of less than \$5600 and decrease in income for richer countries.

It is interesting that the non-linearity is in the expected direction (i.e. inverted-U shaped, as predicted by the theory) for floods, windstorms (with a turning point of \$4688) and landslides (turning point of \$3360, but not statistically significant), whose likelihood and severity are more closely linked to human behavioral choices (e.g. mitigation such as dam construction, or location choices closer to coasts or flood plains) than, say, extreme temperature events.[10] Our theoretical analysis argued for the inverted-U shaped relationship on the basis of changing behavioral choices with respect to mitigation and location at different levels of income.

Since location choice is one possible behavioral factor that can lead to a non-linear relationship between changing income levels and disaster risk exposure, the estimates in Table 3 also control for the urbanization rate and an interaction term between urbanization and GDP per capita. Urbanization rates have statistically significant impacts on deaths for earthquakes, landslides and windstorms but do not appear to influence deaths

[7] In our data set, the mean of the dependent variable is 18.4 while the standard deviation is 85.6; a fairly strong rejection of the Poisson assumption that the mean and standard deviation are identical.

[8] To test whether rich nations experience more disaster events than poor nations we conducted event count regressions for each disaster type. That is, for each disaster type we regressed (using a negative binomial specification) the number of events on GDP per capita, urbanization, population and country and time specific fixed effects. For total disasters, landslides, windstorms, and earthquakes, richer nations have no statistically significant differences in the number of disaster events than poor countries. However, a \$1000 increase in GDP per capita will tend to increase the number of extreme temperature events by 0.29 per year and decrease the number of flood events by 0.11 per year.

[9] Specifications using higher order cubic terms in GDP/capita were also tested. Since the squared specification is nested in the cubic structure we conducted likelihood ratio tests for each of the disaster specifications and failed to reject the restrictions imposed by the squared specification (for every disaster type). This implies that the cubic specification does not yield any statistically meaningful explanatory power over the squared specification. Therefore, in the interest of parsimony we only report the squared specifications.

[10] The U-shaped curve implied by the negative coefficient on GDP and the positive coefficient on GDP's square, as well as the insignificant population variable, for earthquakes are less intuitive. However, this seems to be driven by a 'China effect' in the data. When the regression in column (3) of Table 3 is run without China, the GDP and GDP squared terms are no longer significant (and thus the U-shaped turning point is no longer significant). However, urbanization and its interaction with GDP remain significant and very similar to what is reported in Table 3. In addition, the population variable becomes positive and significant.

Table 1
Pooled GLS and negative binomial estimates

Variable	Total disasters		Floods		Earthquakes		Landslides		Windstorms		Ext. temperature	
	GLS	NB	GLS	NB	GLS	NB	GLS	NB	GLS	NB	GLS	NB
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log (GDP per capita)	−0.126***	−0.857***	−0.100***	−0.343***	−0.020**	−0.185	−0.010*	−0.178	−0.094***	−0.754***	−0.020***	0.110
	(0.023)	(0.101)	(0.019)	(0.071)	(0.010)	(0.205)	(0.005)	(0.126)	(0.017)	(0.126)	(0.008)	(0.197)
Log (Total population)	0.325***	0.742***	0.176***	0.463***	0.027***	0.178*	0.018***	0.136*	0.151***	0.091	0.019***	0.341***
	(0.024)	(0.050)	(0.023)	(0.056)	(0.008)	(0.097)	(0.004)	(0.073)	(0.016)	(0.073)	(0.004)	(0.127)
Total # of natural disaster events	0.442***	1.385***										
	(0.037)	(0.139)										
Total # of flood events			0.990***	5.482***								
			(0.099)	(0.180)								
Total # of earthquake events					1.610***	10.360***						
					(0.089)	(0.381)						
Total # of landslide events							2.281***	8.289***				
							(0.106)	(0.314)				
Total # of windstorm events									0.570***	6.625***		
									(0.060)	(0.228)		
Total # of extreme temperature events											2.295***	9.700***
											(0.146)	(0.546)
Observations	3271	3271	3271	3271	3271	3271	3271	3271	3271	3271	3271	3271
Number of Countries	133	133	133	133	133	133	133	133	133	133	133	133
R-squared	0.52		0.55		0.55		0.81		0.47		0.67	
Country Fixed Effects	No	No										
Year Dummies	No	No										
Log likelihood	−7916.77		−4387.32		−1616.56		−1247.03		−3430.58		−700.66	

Robust standard errors in parentheses.

For NB specifications the dependent variable is the total number of people killed. For GLS specifications the dependent variable is Ln(the number of people killed + 1).

* Significant at the 10% level.

** Idem, 5%.

*** Idem, 1%.

Table 2
GLS and negative binomial estimates with country and time specific fixed effects

Variable	Total disasters		Floods		Earthquakes		Landslides		Windstorms		Ext. temperature	
	GLS	NB	GLS	NB	GLS	NB	GLS	NB	GLS	NB	GLS	NB
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log (GDP per capita)	−0.339**	0.199***	0.189*	0.092*	−0.138	0.078	0.016	0.029	−0.076	0.107*	0.075**	−0.238
	(0.137)	(0.037)	(0.113)	(0.047)	(0.111)	(0.097)	(0.050)	(0.116)	(0.099)	(0.055)	(0.036)	(0.168)
Log (Total population)	0.249	0.302***	0.391**	0.411***	−0.027	−0.045	0.019	0.270***	−0.102	0.379***	0.154**	−0.020
	(0.233)	(0.025)	(0.155)	(0.036)	(0.114)	(0.052)	(0.050)	(0.072)	(0.164)	(0.034)	(0.067)	(0.110)
Total # of natural disaster events	0.376***	0.081***										
	(0.046)	(0.007)										
Total # of flood events			0.846***	0.295***								
			(0.106)	(0.016)								
Total # of earthquake events					1.541***	1.074***						
					(0.090)	(0.061)						
Total # of landslide events							2.193***	1.518***				
							(0.110)	(0.074)				
Total # of windstorm events									0.414***	0.166***		
									(0.062)	(0.009)		
Total # of extreme temperature events											2.003***	2.354***
											(0.129)	(0.158)
Observations	3271	2955	3271	2371	3271	1151	3271	1230	3271	2062	3271	754
Number of countries	133	119	133	95	133	46	133	50	133	82	133	30
Log Likelihood		−6499.63		−3745.15		−1292.25		−1020.74		−2776.34		−513.56
R-squared	0.66		0.66		0.58		0.83		0.64		0.75	

Robust standard errors in parentheses.
For NB specifications the dependent variable is the total number of people killed. For GLS specifications the dependent variable is Ln(the number of people killed + 1).
* Significant at the 10% level.
** Idem, 5%.
*** Idem, 1%.

Table 3
Negative binomial estimates non-linear in GDP and urbanization

Variable	Total disasters (1)	Floods (2)	Earthquakes (3)	Landslides (4)	Windstorms (5)	Extreme temperature (6)
Log (GDP per capita)	1.063	3.727***	−5.765**	2.935	3.779**	−4.785
	(0.942)	(1.292)	(2.937)	(2.888)	(1.501)	(4.321)
Log (GDP per capita)^2	−0.063	−0.234***	0.395**	−0.272	−0.277***	0.251
	(0.065)	(0.090)	(0.201)	(0.202)	(0.105)	(0.297)
Log (GDP per capita) × (% of pop living in an urban area)	0.001	0.005	−0.023**	0.029**	0.018***	0.011
	(0.004)	(0.005)	(0.011)	(0.011)	(0.006)	(0.018)
% Of population living in an urban area	−0.005	−0.043	0.211**	−0.223**	−0.148***	−0.114
	(0.030)	(0.041)	(0.093)	(0.093)	(0.050)	(0.153)
Log (Total population)	0.296***	0.406***	−0.024	0.268***	0.333***	−0.087
	(0.025)	(0.036)	(0.059)	(0.074)	(0.036)	(0.123)
Total # of natural disaster events	0.086***					
	(0.007)					
Total # of flood events		0.308***				
		(0.017)				
Total # of earthquake events			1.100***			
			(0.062)			
Total # of landslide events				1.565***		
				(0.078)		
Total # of windstorm events					0.194***	
					(0.012)	
Total # of extreme temperature events						2.344***
						(0.160)
Observations	2955	2371	1151	1230	2062	754
Number of countries	119	95	46	50	82	30
Log-likelihood	−6496.20	−3738.20	−1287.10	−1014.70	−2755.10	−508.10
Likelihood ratio test statistic/χ^2	4.92*	1.08	10.22***	9.47***	9.39***	1.86
[2pt] Implied turning point (GDP/capita)	6706	5609***	5665***	3360**	4688***	4705
U or inverted-U (IU) shaped	IU	IU	U	IU	IU	U

Robust standard errors in parentheses.
Significance levels for the *implied turning points* are based on a non-linear Wald test with standard errors computed using the delta method.
* Significant at the 10% level.
** Idem, 5%.
*** Idem, 1%.

from floods or extreme temperature events. The significant and positive urbanization coefficient and its negative interaction with GDP per capita indicates that low income highly urbanized countries will see higher levels of deaths from earthquake disasters than similarly urbanized high income countries. This is consistent with the idea that building codes and the engineering quality of structures tend to improve in higher income, developed economies.

The negative coefficients for urbanization and positive coefficients with respect to the interaction of urbanization and GDP per capita for landslides and windstorms at first appear perplexing. It implies that the marginal effect of urbanization in low income countries is negative for landslides and windstorms while the marginal effect of greater urbanization in high income countries is positive. One very plausible explanation for this result is suggested by the work of Rappaport and Sachs (2003) who document that as income has grown in the United States, people have tended to concentrate near oceans, lakes, and along major rivers. These locations tend to be highly productive and offer a high quality of life, but also tend to be places that are more prone to windstorms (i.e. Florida and the Gulf Coast) or near mountainous regions (i.e. California or the Pacific Northwest Coast) where landslides are more likely to occur.[11]

[11] Note that our urbanization measure in this paper gives us cross country and within country variation in *total* urban population. However, to the extent that the spatial allocation of urban centers are changing over time (i.e. from inland areas to more disaster prone

Further, Henderson (2002) suggests that in developing countries urbanization just increases the size of a few 'mega-cities' within a country, while developed countries with advanced transportation infrastructure and communication networks possess a greater number of decentralized urban locations. To the extent that mega-cities in developing countries become mega-cities at least in part due to being historically less prone to major disasters geographically, greater urbanization toward the mega-city may encourage people to move to less disaster prone locations within the country. As income grows and infrastructure improves, urban centers may move away from the mega-city towards more diverse, and possibly more disaster prone areas.[12]

In Fig. 5, we construct income to disaster death functions for floods, landslides and windstorms based on the negative binomial estimates in Table 3, and highlight three separate regions on the graph. Region I represents those on the upward sloping portion of the curves ($0–$3000), Region II are those near the peak of the curves ($3001–$6000), and Region III represents those on the downward sloping portion of the curves (greater than $6000). The most striking thing about Fig. 5 is that as of the year 2000, 58 of the 133 countries in our sample were in either Region I or Region II. That is, 58 of the world's least developed countries may still face increased death from flood, landslide, or windstorm disasters as their incomes grow.

Since our fixed effect estimates only rely on within-country variation in the data, they indicate that as these countries get richer, deaths from floods and windstorms are expected to rise before they fall. A disaster mitigation strategy that emphasizes "wait to get richer" would be misguided for such countries if such a strategy does not also include interventions aimed at changing behavioral choices such as the amount of disaster mitigation to undertake, location incentives, or protection of environmental resources.

What is the effect of increasing urbanization on Region I vs. Region III countries? In 2000, the mean GDP/capita for Region I countries was $1502, while for Region III countries it was $18,705. The mean number of deaths from windstorms and landslides per 100,000 population was 0.15 and 0.11, respectively, in Region I countries and 0.03 and 0.05 in Region III countries. Holding income constant, the estimates in Table 3 indicate that a 1 percentage point increase in urbanization will decrease windstorm and landslide deaths by 0.016 and 0.011 per 100,000 people, respectively. This translates into approximately a 50% reduction in windstorm deaths and a 20% reduction in landslide deaths.

In Region III countries, that same 1% increase in urbanization (holding income constant) would result in increases in the number of deaths from windstorms and landslides of 0.029 and 0.061. This effectively implies a doubling of the number of deaths. These partial equilibrium results where income is held constant must be taken with caution, however. To the extent that urbanization is positively correlated with GDP per capita, then rising income due to urbanization will tend to have a negative effect on Region I countries (thus mitigating the positive marginal urbanization effect), and a positive effect on Region III countries (again, mitigating the negative marginal urbanization effect).

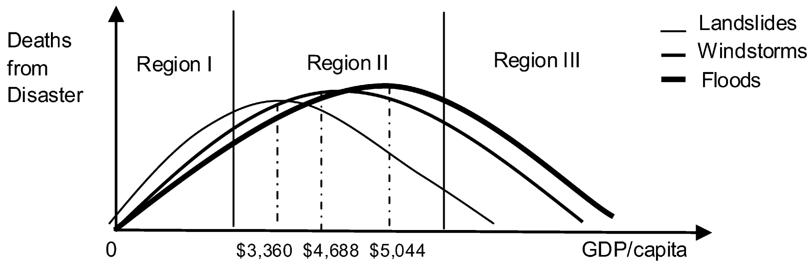
6. Conclusions

Recent large scale natural disasters have brought natural disaster mitigation back to the forefront of policy debates in many countries throughout the world. Many policy analysts appear to have been swayed by the monotonic negative relationship between development and the risk of death from natural disasters that the current academic literature on the topic reports. In this paper we explore this relationship more closely using cross-country panel data, motivated by a conceptual analysis of possible behavioral reactions to disaster risk that argue for a more complicated non-linear relationship. We find evidence that for the types of disasters whose exposure risk is more related to behavioral choices (i.e. floods, landslides, and windstorms rather than extreme temperatures), there is indeed a non-linear relationship where disaster deaths increase with rising income before they decrease. In particular, we find that while countries have a GDP per capita level below roughly $4500–$5500, disaster deaths increase in income, but start decreasing once those countries continue to get richer beyond that turning point.

The main policy implication of this research is that the achievement of the simultaneous goals of natural disaster risk reduction and poverty elimination cannot be assumed to be complementary for all disaster types. This paper highlights the fact that it is quite possible that risk averse individuals will make different risk-return trade-off choices at different income levels. For the poorest nations in the world, the marginal benefit

coastal areas), our urban measure may be picking up unobserved spatial effects changes in urban locations.

[12] For example, think of the urban neighborhoods where houses are built on steep cliffs along the southern California coast, or the growth in Florida communities in Hurricane prone areas.



Region I Countries		Region II Countries		Region III Countries	
Country	2000 GDP/Capita	Country	2000 GDP/Capita	Country	2000 GDP/Capita
Sierra Leone	427	Syria	3,067	Brazil	6,781
Burundi	552	Sri Lanka	3,181	Grenada	6,818
Guinea-Bissau	729	Morocco	3,195	Uruguay	8,130
Madagascar	757	Egypt	3,253	Costa Rica	8,175
Chad	796	Jamaica	3,370	Mexico	8,182
Mozambique	804	China	3,547	Malaysia	8,217
Nigeria	808	Jordan	3,597	Trinidad and Tobago	8,221
Benin	895	Guatemala	3,633	Chile	8,412
Kenya	922	Philippines	3,668	South Africa	8,667
Central African Rep	1,067	Swaziland	4,024	Mauritius	8,858
Uganda	1,164	Paraguay	4,211	Antigua and Barbuda	9,380
Nepal	1,216	El Salvador	4,307	Argentina	11,131
Senegal	1,366	Cape Verde	4,315	Hungary	11,301
Lao PDR	1,418	Belarus	4,405	Oman	11,498
Bangladesh	1,427	Fiji	4,477	Saudi Arabia	11,542
Mongolia	1,491	Algeria	4,979	Korea, Rep.	13,958
Comoros	1,494	Belize	5,124	Barbados	14,084
Haiti	1,512	Venezuela	5,174	Greece	15,280
Mauritania	1,689	Iran	5,460	Bahamas	15,306
Georgia	1,722	Dominica	5,470	Cyprus	15,693
Solomon Islands	1,726	Colombia	5,618	Portugal	15,879
Pakistan	1,751	Dominican Republic	5,643	Macao, China	17,559
Guinea	1,806	Bulgaria	5,714	Spain	18,314
Lesotho	1,994	Turkey	5,731	New Zealand	18,481
Papua New Guinea	2,194	Panama	5,763	Israel	18,895
India	2,220	Tonga	5,787	Puerto Rico	20,438
Nicaragua	2,279	Thailand	5,846	Sweden	22,498
Honduras	2,306			United Kingdom	22,652
Zimbabwe	2,372			Italy	22,875
Indonesia	2,807			Finland	23,075
Vanuatu	2,855			France	23,225
				Japan	23,828
				Germany	23,913
				Australia	24,013
				Belgium	24,250
				Netherlands	24,833
				Canada	25,456
				Austria	25,694
				Switzerland	25,803
				Denmark	26,883
				Ireland	27,612
				USA	31,338
				Norway	32,228
				Luxembourg	51,637

Fig. 5. Turning points for landslides, floods, and windstorms.

of cutting down a forest to make way for a new hotel, shrimp farm, or agricultural land can outweigh the marginal cost associated with an uncertain disaster event such as a flood or landslide that is possibly linked to that economic activity. Similarly, a poor household may find it in their interest to re-locate to a dense urban area in search of better employment opportunities even if it means increasing its exposure to disasters while a richer household may not find it in their interest to do so. Without adequate disaster planning, development policy aimed simply at poverty elimination through economic development could increase the risks associated with natural disasters in the least developed countries of the world.

While we find ample evidence in this paper for a non-linear relationship between economic development and natural disaster deaths, empirically we have only shown the reduced form non-linear relationship between economic development and disaster risk in the aggregate data. Future work that can isolate micro level mechanisms by directly examining individual or household choices should be a fruitful area of research to deepen our understanding of the relationship between development and natural disasters.

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Appendix Table 1
List of countries in the sample

Albania	El Salvador	Madagascar	Switzerland
Algeria	Estonia	Malaysia	Syrian Arab Republic
Angola	Ethiopia	Mali	Thailand
Antigua and Barbuda	Fiji	Malta	Togo
Argentina	Finland	Mauritania	Tonga
Australia	France	Mauritius	Trinidad and Tobago
Austria	Gabon	Mexico	Tunisia
Azerbaijan	Gambia	Mongolia	Turkey
Bahamas	Georgia	Morocco	Uganda
Bahrain	Germany	Mozambique	United Kingdom
Bangladesh	Ghana	Namibia	USA
Barbados	Greece	Nepal	Uruguay
Belarus	Grenada	Netherlands	Vanuatu
Belgium	Guatemala	New Zealand	Venezuela, RB
Belize	Guinea	Nicaragua	Zambia
Benin	Guinea-Bissau	Niger	Zimbabwe
Bolivia	Guyana	Nigeria	
Botswana	Haiti	Norway	
Brazil	Honduras	Oman	
Bulgaria	Hungary	Pakistan	
Burkina Faso	Iceland	Panama	
Burundi	India	Papua New Guinea	
Cameroon	Indonesia	Paraguay	
Canada	Iran, Islamic Rep.	Peru	
Cape Verde	Ireland	Philippines	
Central African Republic	Israel	Portugal	
Chad	Italy	Puerto Rico	
Chile	Jamaica	Rwanda	
China	Japan	Saudi Arabia	
Colombia	Jordan	Senegal	
Comoros	Kenya	Sierra Leone	
Costa Rica	Korea, Rep.	Singapore	
Cote d'Ivoire	Kuwait	Solomon Islands	
Cyprus	Kyrgyz Republic	South Africa	
Denmark	Lao PDR	Spain	
Dominica	Latvia	Sri Lanka	
Dominican Republic	Lesotho	Sudan	
Ecuador	Luxembourg	Swaziland	
Egypt	Macao, China	Sweden	

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