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Review

Revisiting the 'disaster and development' debate – Toward a broader understanding of macroeconomic risk and resilience

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ABSTRACT

Debate regarding the relationship between socioeconomic development and natural disasters remains at the fore of global discussions, as the potential risk from climate extremes and uncertainty pose an increasing threat to developmental prospects. This study reviews statistical investigations of disaster and development linkages, across topics of macroeconomic growth, public governance and others to identify key challenges to the current approach to macro-level statistical investigation. Both theoretically and qualitatively, disaster is known to affect development through a number of channels: haphazard development, weak institutions, lack of social safety nets and short-termism of our decision-making practices are some of the factors that drive natural disaster risk. Developmental potentials, including the prospects for sustainable and equitable growth, are in turn threatened by such accumulation of disaster risks. However, quantitative evidence regarding these complex causality chains remains contested due to several reasons. A number of theoretical and methodological limitations have been identified, including the use of GDP as a proxy measurement of welfare, issues with natural disaster damage reporting and the adoption of ad hoc model specifications and variables, which render interpretation and cross-comparison of statistical analysis difficult. Additionally, while greater attention is paid to economic and institutional parameters such as GDP, remittance, corruption and public expenditure as opposed to hard-to-quantify yet critical factors such as environmental conditions and social vulnerabilities. These are gaps in our approach that hamper our comprehensive understanding of the disaster-development nexus. Important areas for further research are identified, including recognizing and addressing the data constraints, incorporating sustainability and equity concerns through alternatives to GDP, and finding novel approaches to examining the complex and dynamic relationships between risk, vulnerability, resilience, adaptive capacity and development.

Contents

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Introduction

Over the past decades, a number of disciplines, including international development, disaster risk analysis, macroeconomics and public policy, have asked "whether disasters are problem *of* or *for* development? (Albala-Bertrand, 1993; Albala-Bertrand, 2013)" This classical debate on natural disaster and development linkages is still at the fore of global discussions as potential risks from climate extremes and uncertainty increasingly pose a threat to our developmental prospects. Theoretical and qualitative understanding that development dynamics drive disaster risks, and disaster risk may constraint development opportunities is now widely accepted (IPCC, 2012). However, quantitative evidence regarding these complex interactions remains contested. For example, a number of recent publications still ask questions such as "[c]an natural disasters have positive consequences? (Hallegatte and Dumas, 2009)", "[a]re natural disasters good for economic growth? (Ahlerup, 2013)" and "[d]oes development reduce fatalities from natural disasters? (Ferreira et al., 2013)".

The specific social-ecological contexts in which disaster risk arises are highly complex, as are their immediate and longer-term implications. The concept of development is equally multi-dimensional. When these complex factors must be framed within statistically testable questions, it is easy to imagine that finding a robust 'yes' or 'no' answer can be extremely challenging. Even on the relatively narrower topic of the relationship between natural disasters and GDP growth implications, international confidence is considered 'medium', as explained in the recent Special Report on Managing the Risk of Extreme Events (SREX) report IPCC, 2012:

> Differences [in estimates of disaster impacts on the macroeconomy] can be partly explained by the lack of a robust counterfactual in some studies (e.g. what would GDP have been if a disaster had not occurred?), failure to account for the informal sector, varying ways of accounting for insurance and aid flows, different patterns of impacts resulting from, for example, earthquakes versus floods, and the fact that national accounting does not record the destruction of assets, but reports relief and reconstruction as additions to GDP (p. 265).

While medium confidence means a certain level of consistency, quality and quantity of evidence along with agreement in their findings, it also indicates that not all relevant questions have been fully and comprehensively examined (IPCC, 2012). With natural disasters risks expected to continue increasing in the foreseeable future, obtaining a clearer understanding of common challenges is crucial. This article revisits the topic of development and disaster linkages and offers an interdisciplinary look at the fundamental theoretical and methodological challenges associated with this body of literature. In particular, the review focuses on statistical investigations conducted at the macro-level and highlights some of the important limitations and areas for further research.[1]

Statistical investigations of this topic are found to be hampered by: the use of GDP as a proxy for welfare, the problem of missing and incomplete natural disaster damage documentation, and the adoption of non-uniform model specifications across and within different academic disciplines which render comparison of modeling results difficult. Furthermore, topics of economic and institutional parameters such as GDP, remittance, corruption and public expenditure are prioritized over factors such as environmental conditions, social vulnerabilities, and human development conditions; these important aspects have not been adequately investigated partly because they are hard to quantify. Without addressing the more fundamental issues of data quality and standardization, theoretical gaps and disciplinary biases, therefore, new approaches based on 'improved modeling specification' will unlikely help us understand the complex dynamics which drive natural disaster risk and development. Instead, further attention should be paid to addressing existing issues of data quality and standardization, developing alternative wealth accounting methodologies, and identifying novel approaches to examining the complex and dynamic relationships between risk, vulnerability, resilience, adaptive capacity and development. Critical reflection on current discourse and analytical approaches is hence needed.

[1] Other important methodological approaches on this topic include catastrophic modeling (Grossi and Kunreuther, 2006), economic simulation models (Rose and Liao, 2005; Rose and Guha, 2004; Okuyama et al., 2004; Okuyama, 2004) and more recently network analysis(Albala-Bertrand, 2013).

The remainder of this article is organized as follows. 'Empirical observation of natural disaster and development trends' overviews the global trends of natural disasters in recent years, summarizing some stylized facts on development and natural disasters. 'Alternative theoretical frameworks for a disaster-development relationship' contrasts diverse theoretical motivations that drive our statistical investigation of this topic. 'Statistical evidence for the natural disaster and development relationship' reviews the findings of existing literature on statistical investigation of natural disasters, identifying key disagreements. 'Methodological limitations' describes major challenges inherent in the statistical inquiry of natural disaster and development relationship. Finally, 'Conclusions and possible ways forward' identifies where future cross-disciplinary research efforts should be directed to improve our understanding of this subject.

Empirical observation of natural disaster and development trends

Empirical evidence over the past few decades illustrates a complex relationship between disasters and development. In general, the recent years have seen a growing trend in regard to direct disaster impacts. Economic damages due to natural disasters have risen from an annual average of $20 billion in the 1990s to approximately $100 billion during 2000–2010 (International Monetary Fund (IMF), 2012). An increase in exposure of both population and assets is perceived as the major driver of increasing economic disaster risk (IPCC, 2012).

Global disaster trends show that low income countries suffer disproportionately in terms of fatalities due to their vulnerability (Fig. 1: top). Of the global population exposed to natural hazards such as earthquakes, cyclones, floods, and droughts, only 11% are found in countries with a low Human Development Index (HDI), yet these countries disproportionately account for 53% of all disaster fatalities from 1980 to 2000 (Nations Development Programme (UNDP), 2004; UNISDR, 2009).

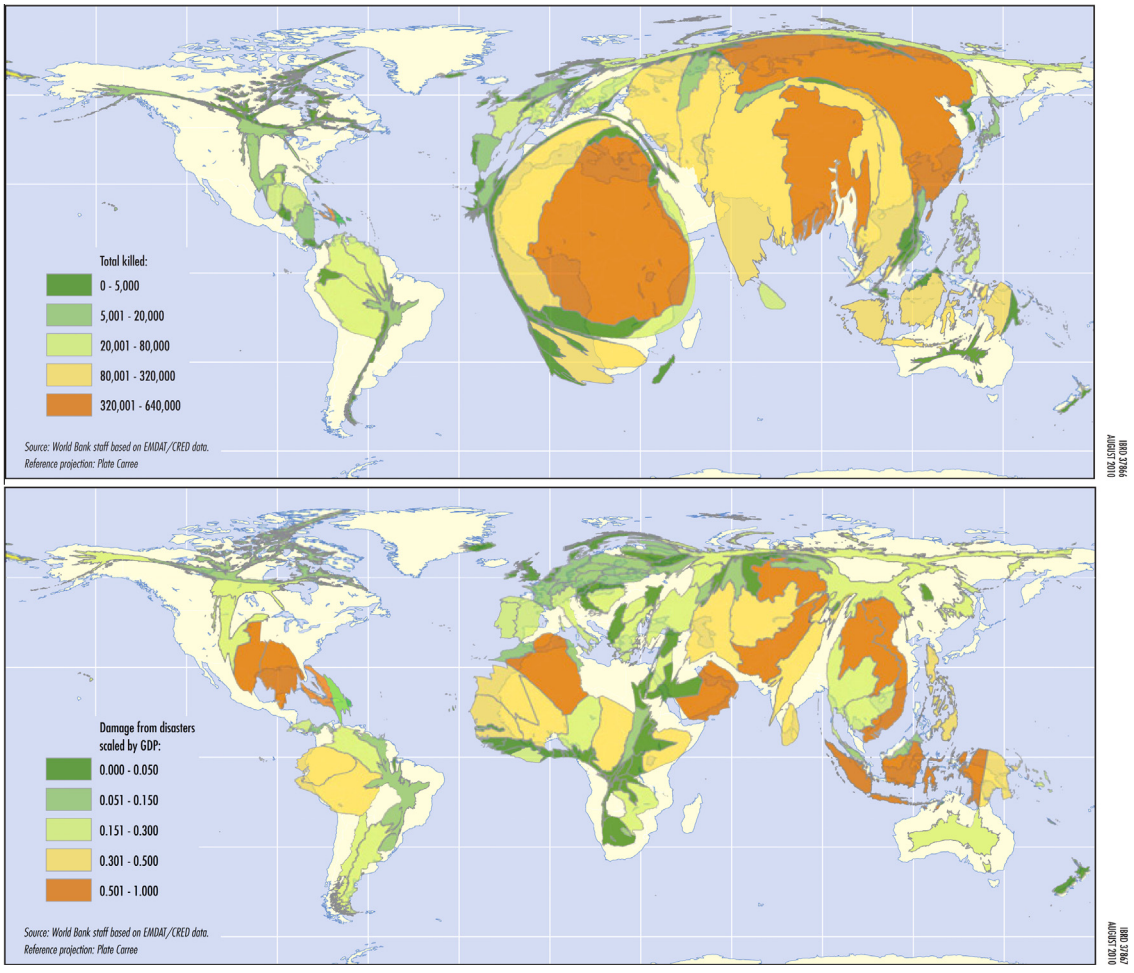

Fig. 1. Global trend in natural disaster fatalities (top) and economic damage per GDP (bottom) from 1970 to 2010. Source: (Nations, 2010).

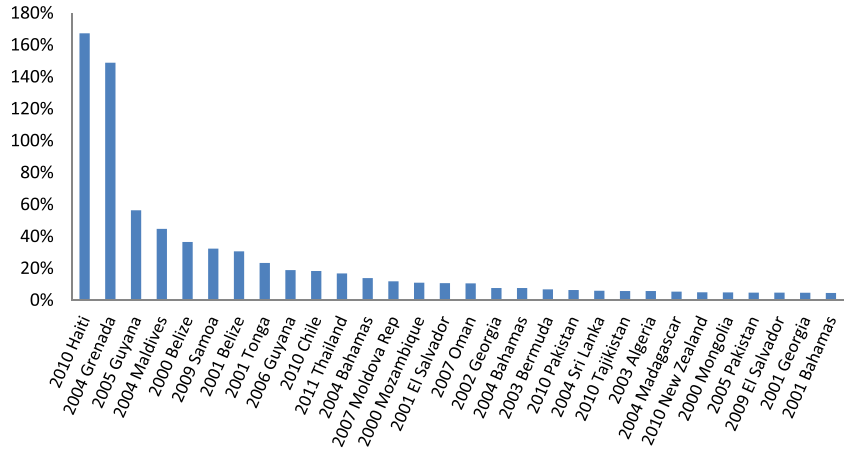

Fig. 2. 30 costliest disasters relative to GDP, 2000–2012. Source: Authors' calculation based on (EM-DAT, 2014) and (World Bank, 2013).

A different picture emerges when we look at the shared burden of economic losses (Fig. 1: bottom) (Nations, 2010). As more people and assets are located in hazard-prone areas of emerging and developed economies, higher economic losses are recorded in these countries. In recent years some of the costliest disasters in absolute terms have occurred in developed and emerging economies, such as the 2005 Hurricane Katrina in the United States ($125 billion), the 2008 Sichuan Earthquake in China ($85 billion), the 2011 Great East Japan Tsunami ($210 billion), and the 2011 Flood in Thailand ($40 billion) (current US$ based on EM-DAT[16]).

Small islands and low income countries, in particular, are highly vulnerable to natural disasters due to their limited ability to absorb large external shocks affecting the economy (World Bank, 2012). The costliest disasters relative to GDP are the 2010 Haiti earthquake (167% of GDP), the 2004 Grenada cyclone (149% of GDP), the 2005 Guyana flood (56% of GDP) and the 2004 Maldives earthquake and tsunami (45% of GDP) (authors' calculation based on EM-DAT (2014) and World Bank (2013) (Fig. 2). Given the precarious public budgetary stance and low insurance penetration of many developing countries, asset destruction caused by natural disasters could severely hamper capital accumulation and growth potential (Baritto, 2009; Mechler, 2009). Their prospects for reconstruction also depend on the largesse of foreign aid, which fluctuates depending on media discourse and other political influences.

While mega-disasters attract global media attention, the majority of disasters are in fact small when evaluated at the macro level, rendering aggregate level analyses challenging. From 2000 to 2013 for example, more than 90% of major natural disasters (i.e. storm, earthquakes, floods and droughts) resulted in less than 1% of all damages relative to GDP (authors' calculation based on EM-DAT (2014) and World Bank (2013); it is likely that many of the even smaller events have been overlooked by these official statistics. Evidence regarding the pervasive impacts of these small events is highly fragmented. In Colombia, for example, total damages from small-scale events between 1972 and 2012 are estimated to be 2.5 times larger than those of large-scale disasters that happened during the same period (World Bank, 2012), however the longer term implication remains unclear. The adverse impacts of these small but frequent disasters are hard to discern using standard economic indicators such as GDP.

The potential occurrence of repeated disaster events means that communities may not recover fully before the next disaster strikes, as Post Disaster Needs Assessments (PDNAs) illustrate. For example, in Khyber Pakhtunkhwa and the states of Azad Jammu and Kashmir in Pakistan, the 2005 earthquake brought devastation to many educational institutions. The same institutions were again affected by the 2010 flood when the reconstruction efforts following the earthquake had hardly been carried out (GFDRR, 2010). In Namibia, many households that were affected by the 2009 floods had not recovered fully from heavy rains in the previous year (Government of Namibia, 2009). As these examples show, years of developmental investments could be eroded by frequent occurrence of natural disasters. These impacts of repeated disasters on household vulnerability and resilience over-time are some of the less understood topics of disaster and development linkages.

Natural disaster may also have pervasive effects on a wide array of sectors; however, complete assessments of indirect impacts are rarely available. Disasters affect a number of socioeconomic aspects indirectly such as public health through post-disaster outbreaks of malaria (Government of Madagascar, 2008; Government of El Salvador, 2009; Republic of Kenya, 2012; Government of Uganda, 2012; Government of Malawi, 2012), acute respiratory illness (Government of El Salvador, 2009; Government of Bangladesh, 2008), enteric diseases (Government of Bangladesh, 2008; Government of Bihar & World Bank, 2010; Government of Myanmar, ASEAN & United Nations, 2008), and mental health issues (Government of El Salvador, 2009; Government of Bangladesh, 2008; Government of Myanmar, ASEAN & United Nations, 2008). Education is also affected, with children temporarily dropping out after drought in Uganda (Government of Uganda, 2012). Also, wildlife habitats experienced increased deforestation during the Kenyan drought due to increased

Table 1
Key research questions raised by diverse academic disciplines on development and disaster linkages. *Source:* the authors.

Relevant disciplines	Key questions
Developmental drivers of natural disaster risk	
Development studies, public policy, geography	• Are the likelihoods of natural disaster occurrence affected by a country's level of socio-economic development and/or institutional/political environment? • Are the extents of natural disaster damages (e.g. fatalities, economic losses and people affected, etc.) affected by a country's level of socio-economic development, institutional/political environment or exposure to natural disasters?
Developmental implications of natural disasters	
Macroeconomics	• Does natural disaster occurrence impact short and long-term GDP growth of a country? • Are natural disaster impacts on economic growth affected by the macroeconomic and socio-economic environment of a country?

charcoal burning (Republic of Kenya, 2012). Because post-disaster appraisals such as PDNAs are conducted for immediate damage assessment only and follow-up studies are rare, we have not yet fully understood the longer-term consequences of such repeated events.

The descriptive evidence of natural impacts in recent years points toward a complex relationship between disasters and development at the macroeconomic level. As will be illustrated, however, investigating such complexity using statistical modeling approaches has been particularly challenging due to a number of reasons. The next section briefly explains a diverse range of theoretical entry points offered by a number of academic disciplines.

Alternative theoretical frameworks for a disaster-development relationship

Various disciplines offer a wide range of theoretical bases for the statistical investigation of disaster and development relationships. The existing body of literature may be classified into those studies investigating whether development affects the probability and extent of natural disaster damage (commonly termed as 'ex-ante' studies) and whether natural disaster occurrence impacts development outcomes, most notably short and long-term GDP, commonly termed as 'ex-post' (Table 1).[2]

Development studies, public policy and geography are some of the disciplines where linkages between ex-ante conditions and disaster impacts have been statistically investigated. A number of contrasting theories are proposed to explain the institutional drivers of disaster risk creation, including the collective action problem (Anbarci et al., 2005), corruption (Escaleras et al., 2007), repressive regimes (Costa, 2012), and the opportunity cost of policy interventions (Keefer et al., 2011; Neumayer et al., 2014). For example, Keefer et al. (2011) examine earthquake disasters globally and suggest that lower hazard frequency and intensity increases the opportunity costs of risk reduction activities such as quake-proofing buildings. A similar argument is put forth by Neumayer et al. (2014) who suggest that "private and public incentives [for mitigation action] are a function of disaster propensity (the expected frequency and magnitude with which hazards strike) (p.2)." Anbarci et al. (2005) offer the alternative view that the obstacles to collective action are embedded in a country's resource constraints and inequality, because a "society's per capita income is simply too low to generate the necessary resources or due to conflict between different segments of society who cannot agree on the distribution of the relative burden of the high costs of effective regulation (p. 1909)." This strand of the literature generally examines the statistical relationship between parameters such as GDP and governance indicators with that of natural disaster parameters including number of disaster occurrences, economic damage and toll on human.

The macroeconomic discipline is another major contributor to the studies of ex-post causality chains. Disaster impact in terms of short-run and long-run macroeconomic growth has been the central focus of analysis, with growth theory providing important theoretical entry points. Most prominently, the so-called 'creative destruction' resulting from disasters is frequently evoked, although evidence seems largely anecdotal (Okuyama, 2003). This theory postulates that a natural disaster offers an opportunity to upgrade productive capital thereby improving the level of technology, which potentially brings developmental benefits to countries:

> Empirical observations indicate that older facilities and equipments [sic] are more prone to receive severe damages than newer ones, and they will be replaced with newer, or sometimes the state-of-the-art, facility and equipments [sic]. This technology replacement, rather than technological progress, can be considered as a positive jump in technology level for production process (Okuyama et al., 2004), and may have sizeable impacts on the growth path after a disaster (Okuyama, 2003).

[2] Although the terms 'ex-ante' and 'ex-post studies' are commonly used for the convenience of categorization, such classification is not without conceptual problems, as socio-economic development and natural disasters are intricately linked. For example the so-called 'ex-post' impact such as GDP growth following a natural disaster event, may in fact be influenced by the level and nature of a country's 'ex-ante' socio-economic development status. While recognizing such limitation, this study uses these terms for the purpose of categorization.

Within the macroeconomic literature, disasters are typically seen as one-time 'exogenous shocks' disrupting the normal workings of an economy or "acts of GOD that are unrelated to any present or past economic variable (Raddatz, 2009)". This perspective contrasts sharply with the hazard-exposure-vulnerability framework, now dominant in the disaster risk management field, which views natural disaster as an integral part of (and lying at the interface of) social and physical systems. Treatment of disasters as exogenous shocks may be typical within macroeconomics, because it is analytically convenient and their models are simplifications by necessity. Yet this approach falls short of appropriately capturing the complex interplay between disasters and development which is of central importance.

Statistical evidence for the natural disaster and development relationship

Statistical analysis of the relationship between natural disasters and development has been greatly fostered by the recent availability of global disaster loss datasets. However, existing studies show considerable variation in their foci and major findings. The reasons behind these variations are both theoretical and methodological in nature: for example, estimating a simple variable such as natural disaster impact is in fact quite complex since one has to choose between the use of either count-oriented indicators (such as the number of natural disasters recorded) or intensity-oriented indicators (such as the number of people affected, recorded economic loss, etc.). Different theoretical frameworks and research questions also lead to the inclusion or exclusion of a wide range of control variables. Alternative model specifications also lead to diverging conclusions.

Overall, existing studies broadly agree that the quality of institutions matters in determining disaster risk and direct and indirect impact (Anbarci et al., 2005; Escaleras et al., 2007; Costa, 2012; Kahn, 2005; Raschky, 2008). Natural disasters, and larger events in particular, are also identified to adversely affect national growth (Raddatz, 2009; Raddatz, 2007; Loayza et al., 2012; Noy, 2009; Hochrainer, 2009). Unsurprisingly, the evidence becomes less conclusive on more specific topics such as the exact functional relationships (e.g. an inverse U or Kuznets curve type of relationship) between income and natural disaster occurrence and magnitude. How factors such as foreign aid, and financial sector maturity affect the natural disaster and development relationship (particularly that of macro-economic growth) remains unclear. The topic of long-term implications of disaster impacts on macroeconomic growth remains controversial (Ahlerup, 2013; Skidmore and Toya, 2002; Kim, 2010).

Developmental drivers of disaster impact

The causal relationship between ex-ante levels of economic development, quality of institutions and disaster impacts has received much attention. Kahn (2005) was one of the earliest works to statistically explore the relationship between institutions and disaster impacts. Analyzing 4300 natural disaster events across 57 countries, the author concludes that richer and poorer nations experience similar frequencies of disasters, but less democratic and more economically unequal countries suffer higher death rates. Anbarci et al. (2005) investigated 269 large earthquakes with 6+ Richter scale ratings that occurred in 26 countries and concluded that economic inequality measured in terms of a land-based GINI coefficient was significantly and positively associated with earthquake fatalities. Escaleras et al. (2007) draws a similar conclusion: their study identified that public sector corruption is significantly and positively related to quake fatalities after analyzing 334 large earthquakes that occurred in 42 countries. Raschky (2008) also finds that countries with more stable governments and better investment climates are associated with fewer disaster fatalities, based on 2792 disaster events recorded from 1984 to 2004. These studies agree that institutional quality matters, especially in lowering natural disaster casualties, even when controlling for the level of economic development. The exceptions include Raschky and Schwindt (2008), whose studies found inconclusive evidence on institutional quality across different natural hazards, (Ferreria et al., 2013), which analyzed 2171 flood events occurred across 92 countries in 1985–2008 and also found that governance does not impact flood fatality significantly when "unobserved country heterogeneity and within-country correlation of standard errors are taken into account (p. 1)."

The exact nature of the relationship between income level and disaster impact is highly contested within literature. Kellenberg and Mobarak (2008) examined observations from 133 countries between 1975 and 2002 and found that the relationship between disaster deaths and per capita GDP is non-linear (Inverse-U shaped) for floods, landslides and windstorms, in which "exposure risk is more related to behavioral choices (p. 799)." Ferreira et al. (2013) offers an alternative perspective, suggesting that the relationship between income level and flooding is more complex. Its impact on flood frequency is negative while its magnitude takes the shape of a U, in which it is negative below per capita GDP of $3934 but increases for higher income levels. These findings are based solely on flood damage analysis and suggest the possibility of a 'safe development paradox' in which populations accumulate risk under the false sense of security provided by levees and other infrastructural protections. Raschky (2008) identified that per capita GDP is linearly related to disaster fatalities, while the relationship is non-linear (U-shaped) for economic damage. Padli et al. (2010) also conclude that non-linear (U-shaped) relationships exist between per capita GDP and economic damage across all timeframes, although such a relationship was less robust for fatalities and numbers of people affected.

Ex-ante drivers relating to broader socio-economic conditions have received relatively less attention as compared to institutions and income. Toya and Skidmore (2007) examined disaster records over the period 1960–2003 in 151 countries and conclude that countries with higher levels of educational attainment, greater openness to trade and more developed financial sectors are significantly correlated with fewer disaster deaths and lower economic damage. Padli et al. (2010) analyzed 73 country records and concluded that factors such as the years of schooling and financial sector development were insignificant in most cases. In the existing body of literature, socioeconomic aspects such as gender equality, the status of health care systems and population characteristics such as age structure and disability have largely been overlooked, as have natural disaster-focused variables such as population's disaster awareness and the availability of natural disaster curricula in formal educational systems. The major findings of these developmental drivers of natural disaster occurrence and damage are summarized in Table 2.

Impacts of disasters on macroeconomic growth

Developmental consequences of natural disasters, particularly in terms of macroeconomic growth, is also a contested topic within literature. The cross-comparison of this strand of literature is made difficult due a number of reasons including the use of diverse indicators. Disaster impacts are measured in many different ways such as number of events (Raddatz, 2009; Raddatz, 2007; Skidmore and Toya, 2002; Cuaresma et al., 2004; Yamamura, 2011; Aurangzeb and Stengos, 2012), fatalities (Noy and Nualsri, 2007; Cavallo et al., 2010), persons affected (McDermott, 2012), people hurt (Loayza et al., 2012), total economic damage (Noy, 2009; Noy and Nualsri, 2007), uninsured economic damage (Peter et al., 2012) or combined indicators (Fomby et al., 2013). Furthermore, the timeframes adopted by these studies ranges from annual (Noy, 2009), through 2–3 years (Ahlerup, 2013), 5 years (Ahlerup, 2013; Loayza et al., 2012; Aurangzeb and Stengos, 2012; Noy and Nualsri, 2007; McDermott, 2012) to decades (Ahlerup, 2013; Skidmore and Toya, 2002; Kim, 2010). Natural hazards are also categorized differently, being analyzed together (Loayza et al., 2012; Noy, 2009; Yamamura, 2011; Noy and Nualsri, 2007), independently (Loayza et al., 2012; Fomby et al., 2013), or grouped into common

Table 2
The effect of development indicators on disaster occurrence and damage.

Hazard					*Exposure*				
Number of disasters		↑[a]		Costa (2012), Kellenberg and Mobarak (2008)	Total population	↓	↑		Anbarci et al. (2005), Escaleras et al. (2007), Raschky (2008), Kellenberg and Mobarak (2008), and Padli and Habibullah (2009)
Magnitude		↑		Ferreira et al. (2013), Anbarci et al. (2005), Escaleras et al. (2007), Keefer et al. (2011), and Raschky and Schwindt (2008)	Percentage of urban population	↓	↑	X	Kellenberg and Mobarak (2008)
Propensity[b]	↓		X	Anbarci et al. (2005), Escaleras et al. (2007), Keefer et al. (2011), and Neumayer et al. (2014)	Land area	↓		X	Anbarci et al. (2005), Costa (2012), Raschky (2008), and Padli and Habibullah (2009)
Vulnerability/Resilience									
Economic					**Human/ Social**				
Per capita GDP	↓	↑	X	Ferreira et al. (2013), Anbarci et al. (2005), Escaleras et al. (2007), Keefer et al. (2011), Kahn (2005), and Raschky (2008)	Schooling	↓		X	Skidmore and Toya (2002), Padli et al. (2010), and Padli and Habibullah (2009)
				Skidmore and Toya (2002), Raschky and Schwindt (2008), Kellenberg and Mobarak (2008), and Padli et al. (2010), Padli and Habibullah (2009)	Ethnic fragmentation	↓		X	Kahn (2005)
GINI coefficient		↑	X	Anbarci et al. (2005) and Kahn (2005)	**Institutional**				
Trade openness	↓		X	Skidmore and Toya (2002) and Raschky and Schwindt (2008)	Democracy	↓		X	Keefer et al. (2011), Kahn (2005), and Raschky and Schwindt (2008)
Foreign aid	↓	↑	X	Costa (2012) and Raschky and Schwindt (2008)	Government stability	↓			Raschky (2008)
Financial sector	↓	↑	X	Skidmore and Toya (2002), and Padli et al. (2010)	Human rights	↓			Costa (2012)
Investment climate	↓			Raschky (2008)	Corruption		↑		Escaleras et al. (2007)
					Size of government	↓	↑	X	Skidmore and Toya (2002) and Padli et al. (2010)

[a] Down and up arrows indicate negative (attenuated) and positive relationship respectively. X indicates an insignificant relationship.
[b] Intensity and frequency.

categories such as geologic, climate and other disasters (Raddatz, 2009; Raddatz, 2007; Skidmore and Toya, 2002; Kim, 2010). Robustness tests are often performed to test whether specific statistical relationships hold for alternative model specifications. Given these variations, interpreting conclusions drawn from these studies are difficult, and merits additional caution.

Macroeconomic variables, and GDP in particular, are the main focus of this strand of research. On short- and mid-term (up to 5 years) implications, a number of studies have found that natural disasters have adverse macroeconomic impacts. For example, Raddatz (2007) investigated geologic, climatic and human disasters (i.e. famine and epidemic) in low income countries and found that climatic and human disasters were associated with 2% and 4% declines in GDP in the year following the event, whereas geological disasters had a small and insignificant effect. Raddatz (2009), then analyzed a larger set of countries and again found a negative macroeconomic impact from climatic disasters, with lower income and smaller economies suffering more after disasters. Hochrainer (2009) produced counterfactual GDPs without disasters using the Autoregressive Integrated Moving Average (ARIMA) model, and compared them to actual observations of 225 large natural disaster events during 1960–2005. The conclusion of this comparison was that disasters on average lead to negative growth in the mid-term, and that aid and remittances attenuate adverse macroeconomic impacts. Noy (2009) also examined a large set of economic and institutional factors which influence the resilience of an economy, and concluded that disaster impacts, as measured in normalized economic damage, had a significant negative effect on short-term outputs.

Table 3
Developmental implications of natural disasters (primarily in terms of GDP).

Short-Run Effect									
Hazards									
Climatic Disasters	↑[a]	↓	X	Raddatz (2009), Raddatz (2007), Loayza et al. (2012), and Fomby et al. (2013)	Combined natural disasters	↑	↓	X	Ahlerup (2013), Loayza et al. (2012), Noy and Nualsri (2007), Noy (2009), Hochrainer (2009), and Jaramillo (2010)
Geological Disasters	↑		X	Ahlerup (2013), Raddatz (2009), Raddatz (2007), Loayza et al. (2012), and Fomby et al. (2013)					
Vulnerability/Resilience									
Economic					**Human/Social**				
Aid	↑		X	Ahlerup (2013), Raddatz (2009), and Hochrainer (2009)	Schooling			X	Noy and Nualsri (2007), and Loayza et al. (2012)
Private credit			X	Loayza et al. (2012)	Fertility		↓	X	Noy and Nualsri (2007)
Inflation		↓	X	Loayza et al. (2012) and Noy (2009)	Illiteracy∗Disaster		↓		Noy (2009)
Trade openness	↑		X	Noy and Nualsri (2007) and Loayza et al. (2012)	**Institutional**				
Remittance	↑	↓	X	Hochrainer (2009)	Institutional Strength∗Disaster	↑			Noy (2009)
Domestic credit∗Disaster	↑			Noy (2009)	Size of government	↑	↓	X	Loayza et al. (2012), Noy (2009), and Noy and Nualsri (2007)
Foreign Exchange Reserve∗Disaster	↑			Noy (2009)					
Long-Run Effect									
Hazard					*Exposure*				
Climatic Disasters	↑	↓		Raddatz (2009), Skidmore and Toya (2002), and Kim (2010)	Combined natural disasters	↑		X	Ahlerup (2013) and Kim (2010)
Geologic Disasters	↑	↓	X	Ahlerup (2013), Skidmore and Toya (2002), Kim (2010), and Raddatz (2009)					
Vulnerability/Resilience									
Economic					**Human/Social**				
Investment to GDP	↑			Skidmore and Toya (2002) and Kim (2010)	Schooling	↑			Skidmore and Toya (2002)
Trade openness	↑			Skidmore and Toya (2002) and Kim (2010)	Fertility		↓		Skidmore and Toya (2002)
Capital stock growth	↑			Skidmore and Toya (2002) and Kim (2010)	**Institutional**				
					Size of government	↑			Kim (2010)

[a] Up and down arrows indicate positive (attenuated) and negative impacts respectively. X indicates an insignificant relationship.

Factors such as literacy rate, openness to trade, foreign exchange reserves and institution were associated with attenuated impacts.

Studies such as Noy and Nualsri (2007), Jaramillo (2010) and Loayza et al. (2012) provide less conclusive evidence however. As Noy and Nualsri (2007) illustrate, the number of people killed in a disaster is significantly and negatively associated with GDP growth using fixed effects and two-step system GMM models, but insignificant using two-step difference GMM estimates. Jaramillo (2010) found that both economic damage as percentage of GDP (incurred over the past 2, 3 and 5 years) and the number of disasters have a significant and positive effect on GDP for countries with low disaster incidence, but the impact is insignificant for medium disaster incidence countries and significant and positive for high disaster incidence countries. Loayza et al. (2012) also found that disaster impacts on overall GDP and sectoral GDP may differ significantly and these also diverge across different hazards. Similarly inconclusive observations were also made by Fomby et al. (2013).

In regards to longer-term impact across decades, Skidmore and Toya (2002) examined the relationship between the frequency of natural disaster occurrence per land area and average GDP growth between 1960 and 1990. They found the incidence of climatic disasters to be positively associated with growth, human capital investment as measured in secondary school enrollment and total factor productivity improvement. Geographic disasters on the other hand were found to be negatively associated with growth. Kim (2010) performed analogous regressions over the 1990–2004 period and concluded that climatic disasters are positively related to human capital investment, whereas geologic disasters hamper it. Using instrumental variables, Ahlerup (Ahlerup, 2013) also found that the frequency of geologic disasters is associated with a higher economic growth rate between 1965 and 2008. Cavallo et al. (2010) used a comparative case studies approach and found that even large disasters do not have a significant effect on long-term economic growth, with the exception of cases where disasters were followed by "radical political revolution, which severely affected the institutional organization of society." Alternative views are provided by studies such as that by Raddatz (2009), who suggests that climatic disasters on average lead to a long-term decline in GDP of 0.6%. In recent years there has been a growth in studies evaluating wider developmental implications of natural disasters such as impacts on income inequality (Yamamura, 2013), human capital formation (McDermott, 2012), international trade (Gassebner et al., 2010), and social capital (Toya and Skidmore, 2012). Table 3 summarizes key findings.

Methodological limitations

Statistical investigation of the disaster and development relationship is faced with a number of methodological limitations. First and foremost, GDP as a proxy measurement of social welfare causes issues in the post-disaster context. GDP is a flow measure which means that damage to capital stock is not recorded, while recovery spending is recorded as a positive entry (Table 4). Furthermore, taking GDP as a measure of national economic production means that important aspects such as distributional consequence are overlooked. Subsistence and informal economies are also difficult to capture (Jerven, 2013; Stiglitz et al., 2009). GDP as a national, aggregate measure also masks devastating welfare impacts that occur at sub-national levels. For example, in the 2009 central African flood, GDP loss is estimated at 0.07% while total income loss experienced by affected households is estimated at 14% of average household income (Government of Senegal, 2010). Similarly in the

Table 4
Disaster Impacts and Limits of GDP. *Source:* The authors.

			Captured by GDP		Impact on GDP/ livelihood*
Damage		Physical destruction of infrastructure and assets	X		↓
Loss	Formal sector	Business interruption and higher-order effects in production		√	↓
		Reduced consumption due to reduced income		√	↓
	Informal / subsistence economy	Business interruption and indirect loss in production	X	√	↓
		Reduced consumption due to reduced income/ subsistence production	X	√	↓
Response /recovery		Infrastructural rehabilitation		√	↑
		Increased public services expenditure (food/medical provision etc.)		√	↑
		Increased import due to post-disaster material and service needs		√	↓
		Increase aid flow due to disasters	X		↑
		Increased remittance flow due to disasters	X		↑

Note: *In cases where data is not reflected in GDP. (√:yes, X: no).

Namibian flood of 2009, aggregate loss in GDP was estimated at 0.6% while income loss in affected regions was estimated to be as high as 13% (Government of Namibia, 2009). The developmental consequences of these disaster impacts are extremely hard to capture using aggregate statistics. Particularly difficult to estimate is the impact of repeated disasters as they cumulatively increase vulnerability to future disasters (Hochrainer-Stigler, 2012).

These issues are further complicated by the problems of natural disaster damage reporting. Felbermayr and Gröschl (2013) illustrates that the likelihood of disaster incidents being documented in the EM-DAT database is strongly related to per capita GDP for quakes, storms and floods, controlling for their magnitude. Such bias in data reporting significantly hampers our ability to draw non-spurious conclusions regarding disaster and development linkages. Natural disaster damage and losses estimates should, in theory, include indirect or higher order effects such as interruption of business activities and non-economic losses such as disruption of ecosystem services and loss of cultural heritage (Rose, 2004). However, complete reporting of such indirect and intangible impacts is rarely available.

Conclusions drawn from statistical models are inherently sensitive to the choice of functional forms and variables included. In addition to the difficulty in measuring natural disaster impacts, the existing literature adopts a variety of proxy indicators to control for non-development factors. For example, researchers have used proxy variables such as total land area, total population and latitudes to control for the effect of geographical variability in hazard occurrence and exposure. Generalized assumptions are used for modeling convenience – such as "[geographically] smaller countries are less able to smooth disaster relief" or "larger populations and those [countries which] are more densely populated have more people who are potentially at risk (Costa, 2012)". Yet these assumptions are contradictory to the disaster risk theory of hazard, exposure, and vulnerability framework, which suggests that "exposed" assets and "exposed" populations matter more than aggregate national figures. A strict treatment of natural disaster risk-related concepts such as 'exposure' is rarely found in existing literature. One exception is Ferreira et al. (2013) who constructed an indicator of exposed populations using flood area and population grid overlays.

Conclusions and possible ways forward

A theory of collective learning suggests there are single, double and triple loop learning possibilities (IPCC, 2012). Applying this theory into the empirical analysis of natural disaster and development, a 'single-loop' frame of mind may ask whether parameters x and y should be included, and in what empirical form should they be transformed. A 'double-loop' frame of mind may then ask whether conventional use of parameters such as GDP is the right approach to begin with. A 'triple-loop' frame of mind may further ask how well the interdisciplinary community as a whole is building knowledge more broadly. It is this 'triple-loop' frame of mind which asks whether our research attention and resources are devoted in the appropriate areas. This paper has brought out these critical questions.

Upon review of existing studies spanning across topics of macroeconomic growth, socio-economic development, public governance and others, systematic issues with our current approach have been highlighted: our continued reliance on GDP as measurement of welfare, the use of missing and incomplete natural disaster damage dataset, and the adoption of a widely varying empirical model specifications and control variables. Together these issues render interpretation and cross-comparison of modeling results difficult and severely hamper the robustness of our knowledge generation. The existing analyses are also biased toward the use of available data, with systemic omission of hard-to-quantify but critical factors such as environmental conditions and social vulnerabilities. The analysis of natural disaster 'damage' as opposed to natural disaster 'risk' also poses a number of issues.

These issues are key methodological limitations that hinder our statistical analysis of the link between disasters and development. Given that these limitations will likely persist in the short to medium term, alternative regression runs using more rigorous statistical methodologies may not necessarily lead to improved understanding of the disaster and development relationship. Further studies are therefore needed to address these fundamental problems. This review identifies a number of important areas for further research.

Knowing and addressing the data constraints

One important area of further research is the improvement of disaster data reporting through the standardization of reporting methods, explicit documentation of direct versus indirect damage and the recording of error margins and uncertainty. In the field of disaster analysis, we do not yet have a complete global dataset recording disaster damage. Countries and events are not recorded evenly across different global regions, levels of income, and the like. Data are inherently biased, because they are collected for different reasons and some methods (e.g. insurance costing) are easier to administer than others. Recognizing these limitations is an important step toward improving our collective knowledge on this topic. Fortunately, methodologies are now available that allow us to estimate the indirect and non-monetary impact of disasters (Meyer and et al., 2013). Also, the emerging field of applied econometrics combines unconventional sources of data such as satellite observations and hydro and meteorological records to reconstruct hazard information. Novel options such as crowd-sourcing also offer exciting avenues for future research.

Beyond the GDP – disaster debate

Alternative measurements of aggregate welfare also deserve further attention. GDP continues to be used as a dominant proxy measurement of welfare, though researchers have recognized that its use is problematic particularly in the context of natural disaster studies and sustainability discourse to move beyond GDP have ensued over the past decades (Mechler, 2009; Stiglitz et al., 2009; Haggart, 2000). Consumption, income inequality and poverty are some of the alternatives which could broaden analysis, yet studies using them remain limited. Stock measures such as financial capital (e.g. savings), physical capital (e.g. infrastructure) and social and human capital (e.g. kinship, health and education) are also important as they represent both the tangible and intangible capacities of an economy, to spur growth through investment and innovation, to promote sustainable development and to handle future disasters (Chambers and Conway, 1992; Bebbington, 1999). A new measurement approach such as disaster-adjusted genuine savings has been proposed with tentative findings on aggregate consumption impacts (Mechler, 2009), and further research would be particularly helpful in investigating how these alternative indicators could be used to guide our analysis.

Sub-national level analysis is another important avenue for further research. Evaluating the heterogeneity of disaster impacts within a country and across time can give important insights regarding the complex dynamic relationships regarding natural disaster and development (Yazdanpanah et al., 2013). As available assessments such as PDNAs show, macro-level implications may mask the debilitating effects of repeated disasters on highly exposed localities. Given the prevalence of small and frequently occurring disasters globally, and the relatively small share of economic output generated by the most vulnerable, further synthesis of macroeconomic analysis with that of meso- and micro-studies would be useful.

Examining risk, vulnerability and resilience as opposed to immediate disaster impacts

Attention to risk and resilience (and adaptive capacity), as opposed to disaster damage, is also needed. This is because the former concepts are dynamic and interlinked (Hochrainer-Stigler et al., 2013), while the latter gives only a snap-shot of these linkages. The absence of disaster occurrence does not imply the absence of risk, but this aspect is insufficiently analyzed in the existing literature (Hochrainer-Stigler, 2012). For example, if a county's initial levels of fiscal and human capacities are sufficient to respond and recover effectively, a catastrophic disaster occurring at time t may result in relatively small aggregate impacts in terms of GDP at time $t + 1$. The same event, however, may well deplete a nation's fiscal capacity (e.g. its reserve fund for natural disasters events), rendering it more vulnerable to the possibility of the next disaster. A simplified question which asks whether, and to what extent, the occurrence of disaster at time t leads to GDP reduction at time $t + 1$, fail to capture a more broader picture—how disaster impact, along with anticipation of the risk and policy intervention taken at time t, affects the capacity of firms, households and communities to proactively manage their risk and pursue economic, social and environmental objectives at time $t + 1$ and beyond.[3] Such cumulative and interlinked impacts are harder to evaluate, and demand novel approaches that go beyond evaluation of recoded damage and immediate impacts.

Framing the disaster and development linkages holistically, it is clear that the desired outcome of development and natural disaster policy is not about getting GDP growth back to its original trajectory, or reducing direct disaster damage. What is crucial is enhancing our capacity to anticipate and proactively manage disaster risks over time at various developmental stages. To understand the factors that foster or erode such ability over time,[4] further attention must be paid to the intangible and less-frequently reported parameters such as human, social and environmental capitals, together with the more-frequently analyzed parameters of financial and physical capitals. Based on such broader framing of natural disaster and development linkages, our question is no longer whether disaster is a problem *of*, or *for* development. Instead, the academic community should collectively ask the question: "what *kind of* development will foster our ability to proactive manage natural disasters risk overtime and *how can we make the most* of pre-and post-disaster opportunities for interventions so that societies may build resilience and adaptive capacity over the long-run?" A narrow focus on the partial correlation between economic losses, fatalities, and GDP growth tells us little about the in-betweens of the complex disaster–development causality chains. More probing analyses beyond GDP and disaster damage are certainly needed to answer such questions.

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Appendix A

See Appendix 1 and 2.

[3] Distinction between expected and unexpected disaster damage and losses is also an important topic related to the economics of natural disasters (Kern, 2010).

[4] Full discussion on concepts of risk, vulnerability, resilience and adaptive capacity are beyond the scope of this paper. For conceptual review of these topics please refer to (Bahadur et al., 2010; Liao, 2012; Folke, 2006; Walker et al., 2004).

Appendix 1
Econometric evidence on hazard, exposure, vulnerability and resilience (dependent variables: fatalities or economic losses).

Independent variables	Summary of evidence
Hazard	
Total number of hazards	– Total number of disasters occurred is significantly and positively related to disaster fatalities Kellenberg and Mobarak (2008).
Magnitude	– The magnitudes of hazards are significantly and positively related to fatalities for storms, floods and earthquakes Raschky and Schwindt (2008). – The magnitudes of quake hazards are significantly and positively associated with economic loss Neumayer et al. (2014). – The magnitudes of quake hazards are significantly and positively associated with higher death rates Anbarci et al. (2005), Escaleras et al. 2007, and Keefer et al. (2011). – The magnitudes of floods are significantly and positively associated with flood fatalities Ferreira et al. (2013).
Magnitude*Population density	– The magnitudes of quake hazards multiplied by population density around epicenter are significantly and positively associated with higher death rates Keefer et al. (2011).
Distance from epicenter	– The distance from the epicenter is negatively associated with earthquake fatalities Anbarci et al. (2005). – The frequency of quakes is not significantly correlated with fatalities Anbarci et al. (2005). – The frequency of quakes is significantly correlated with fewer deaths Escaleras et al. (2007).
Disaster propensity	– Higher disaster propensity of an earthquake is significantly correlated with fewer deaths Keefer et al. (2011). – Higher disaster propensity of an earthquake is significantly correlated with lower economic loss Neumayer et al. (2014).
Exposure	
Total population	– The number of total population is significant and negatively correlated with economic damage/GDP and fatality per capita Raschky (2008). – The number of total population is significantly and positively related to disaster fatalities Padli and Habibullah, 2009. – The number of total population is significantly and positively related to quake fatalities Anbarci et al. (2005) and Escaleras et al. (2007). – The number of total population is significantly and positively related to disaster fatalities for total disasters combined (floods, landslides and windstorms) but is insignificantly related to earthquake and extreme temperature fatalities Kellenberg and Mobarak (2008).
Land area	– Land area is insignificant in affecting disaster economic damage/GDP and per capita fatalities Raschky (2008). – Land area is significantly and negatively related to natural disaster fatalities Padli and Habibullah (2009). – Evidence is inconclusive on the impact of land area on earthquake fatalities Anbarci et al. (2005). – Land area is insignificant in explaining natural disaster death rates Costa (2012).
% Urban	– % of urban population is significantly and positively related to earthquake fatalities, significantly and negatively related to landslides and windstorm fatalities, insignificantly related to total disasters, floods, and extreme temperature fatalities Kellenberg and Mobarak (2008).
Latitude	– Latitude is significantly and negatively related to flood fatalities, but insignificantly related to storm and earthquake fatalities Raschky and Schwindt (2008).
Elevation	– Elevation is significantly and negatively related to fatalities for storms and earthquakes but positively related to flood fatalities Raschky and Schwindt (2008).
Vulnerability/Resilience	
Economic:	
Per capita GDP	– Higher income is significantly correlated with reduced earthquake fatalities Anbarci et al. (2005) and Escaleras et al. (2007). – Higher income is significantly correlated with fewer deaths but insignificantly related to lower damage/GDP Toya and Skidmore (2007). – Higher income is significantly correlated with fewer deaths for storms but evidence is inconclusive for floods and earthquakes Raschky and Schwindt (2008). – Higher income is significantly related to fewer quake deaths for some specifications but evidence is not as robust in other specifications Keefer et al. (2011). – Higher income is associated with fewer disaster deaths Kahn (2005). – Non-linear U-shaped relationship between per capita GDP and disaster economic damage/GDP Raschky (2008) and Padli et al. (2010). – Non-linear U-shaped relationship between per capita GDP and fatalities Padli and Habibullah (2009). – Non-linear U-shaped relationships between per capita GDP and fatalities and the number of people affected were found for 1985, but for the remaining years the relationship was found to be linear Padli et al. (2010). – Linear (negative) relationship between per capita GDP and fatalities Raschky (2008). – Income is significantly and negatively associated with flood frequency, and is also significantly and non-linearly (U-Shaped) related to flood magnitude. The effect on income on flood fatalities controlling for magnitude is weakly significant and negative Ferreira et al. (2013).
GINI coefficient	– Land-based GINI is a significant factor reducing earthquake fatalities. Income-based GINI is inconclusive Anbarci et al. (2005). – Higher income inequality is associated with higher natural disaster death rates Kahn (2005).
Aid	– Past foreign aid is positively and significantly correlated with higher death tolls for storms. For floods and earthquakes, it increases the probability that the death toll is non-zero but reduces fatalities Raschky and Schwindt (2008). – The amount of foreign aid is not a significant factor explaining natural disaster death rates Costa (2012).
Trade openness	– Trade openness is significantly and negatively correlated with economic loss per GDP and fatalities Toya and Skidmore (2007). – Trade openness is significantly and negatively correlated with flood and earthquake deaths but insignificantly related to storm deaths Raschky and Schwindt (2008).

Appendix 1 (*continued*)

Independent variables	Summary of evidence
Financial sector	– A more developed financial sector (higher M3/GDP) is significantly associated with fewer fatalities but its relation to economic damage/GDP is insignificant Toya and Skidmore (2007). – A more developed financial sector (higher M2/GDP) was significantly and positively associated with economic damage/GDP for 1985 and 1995 but insignificant for 2005 Padli et al. (2010).
Investment climate	– Investment climate (i.e. risk of expropriation or contract law according to the international country risk guide) is significantly and negatively correlated with disaster economic damage/GDP and per capita fatalities Raschky (2008).
Human:	
Schooling	– Years of schooling is significantly and negatively correlated to both economic damage/GDP and fatalities Toya and Skidmore (2007). – Secondary school enrollment is significantly and negatively related to natural disaster fatalities Padli and Habibullah (2009). – Years of schooling is found to be insignificant in all cases (economic damage/GDP and the number of people affected), except for fatalities (negative and significant) for the sample year 2005 Padli et al. (2010). – Less democratic nations are associated with higher disaster fatalities (the effects could not be found for individual disasters) Kahn (2005).
Institutional:	
Democracy	– Less democratic nations are associated with higher storm fatalities but lower earthquake fatalities, while its impact on floods is insignificant Raschky and Schwindt (2008). – Less democratic nations are associated with higher quake death rates Keefer et al. (2011).
Corruption	– Public sector corruption is positively and significantly correlated with earthquake fatalities Escaleras et al. (2007).
Ethnic fragmentation	– Countries with higher ethnic fragmentation experience lower natural disaster death rates using zero-inflated negative binomial (ZINB) regression. The effect is insignificant in explaining quake deaths using ordinary least squares (OLS) model Kahn (2005).
Government stability	– Government stability is significantly and negatively correlated with disaster economic damage/GDP and per capital fatalities Raschky (2008).
Government effectiveness	– The perceived effectiveness of government (based on Kaufmann et al. 2008) is significantly and negatively associated with flood and earthquake fatalities, but its impact on storm fatalities is insignificant Raschky and Schwindt (2008).
Rule of law	– The perceived rule of law (based on Kaufmann et al, 2008) is significantly and negatively related to flood fatalities but its impact on storm and earthquake fatalities is insignificant Raschky and Schwindt (2008).
Human rights record	– The worse the human rights record, the higher the number of deaths with an inverse-U shape relationship Costa (2012).
Size of government	– Size of government (government consumption/GDP) is significantly and positively correlated with fatalities but the relationship is insignificant for economic damage as percentage of GDP Toya and Skidmore (2007). – Size of government (government consumption/GDP) is significantly and negatively related to the number of people affected for all timeframes analyzed, but the evidence was inconclusive for fatalities and economic damage/GDP Gassebner et al. (2010).

Note: The list includes evidence that is not as conclusive due to alternative model specifications and sub-groups adopted for other robustness checks. Please refer to each study for complete details of their findings.

Appendix 2

Econometric evidence of disaster impacts on growth and development (dependent variables: per capita GDP, GINI coefficient, R&D expenditure, etc.)

Independent variables/ subgroup categories*	Summary of evidence
Short-run findings:	
Disasters	
Climatic	– Climatic disasters reduce per capita GDP by 2% a year after the event (the impacts virtually disappear five years after the event) Raddatz (2007). – Climatic disasters have a negative and significant impact on per capita GDP (an average long-run effect of −0.6% in which approximately 0.5% is felt in the year of the event) Mechler (2009). – Flood impacts as measured in the number of people hurt normalized by population size significantly and positively affect the overall GDP growth and agricultural GDP growth. Drought significantly and negatively affects agricultural GDP Loayza et al. (2012). – Cumulative effects on GDP growth were negative for drought but positive for floods. Storms had no significant effects on GDP growth Fomby et al. (2013).
Geologic	– Geologic disasters have a small and insignificant impact on per capita GDP Raddatz (2009), Raddatz (2007), and Loayza et al. (2012). – Geologic disasters are significantly and positively related to GDP growth using fixed effects OLS models but are insignificant using the fixed effects IV models Ahlerup (2013). – Earthquakes had no significant effect on GDP growth Fomby et al. (2013).
Combined disasters	– Property damage caused by a disasters negatively impacts GDP growth in the same year. Neither population affected nor killed are statistically significant determinants of post-disaster GDP growth Noy (2009). – A higher number of people killed in a disaster is associated with lower GDP growth using fixed effects and two-step system generalized method of moments (GMM) estimates but this variable is insignificant using two-step difference GMM estimates Noy and Nualsri (2007). – Economic damage of disaster as % of GDP is an insignificant determinant of growth Noy and Nualsri (2007).

(*continued on next page*)

Appendix 2 (*continued*)

Independent variables/ subgroup categories*	Summary of evidence
	– Disasters as measured by the number of people hurt normalized by population size does not significantly affect overall GDP growth. It does significantly and negatively impact agricultural GDP Loayza et al. (2012). – Disasters as measured in the number of events recorded are significantly and positively related to per capita GDP Ahlerup (2013). – The differences in GDP growth between disaster years and counterfactual scenarios are statistically significant (disaster negatively impacts GDP growth) Hochrainer (2009). – Contemporary economic damage (occurred over the past 2, 3, or 5 years) has a significant and positive effect on GDP for countries with low disaster incidence, while the impact is insignificant for medium disaster incident countries and significant and positive for high disaster incident countries Jaramillo (2010).
Vulnerability and Resilience	
Economic:	
Income level	– Low-income countries suffer greater per capita GDP loss due to climatic disasters (approximately 1% as opposed to 0.5% (middle) and 0.25 high income) countries) Raddatz (2009). – Higher per capita GDP interacts with disaster damage and significantly attenuates output decline Noy (2009). – Initial per capita GDP is not a significant factor affecting GDP growth Loayza et al. (2012).
Indebtedness	– A country's initial level of indebtedness does not impact output loss from climate disaster Raddatz (2009). – Inflation is not a significant factor affecting GDP growth Noy (2009).
Inflation	– Inflation significantly and negatively affects GDP growth Loayza et al. (2012).
Stock market capitalization	– Stock market capitalization (as % of GDP) interacting with disaster damage does not significantly affect GDP growth Noy (2009).
Domestic credit	– Domestic credit by banking sector (as % of GDP) interacting with disaster damage significantly attenuates GDP growth Noy (2009).
Capital account openness	– Capital openness interacting with disaster damage shows inconclusive evidence (significantly worse GDP growth when using indicators based on Chinh and Ito (2006) but insignificant when using that of Edwards (2007)) Noy (2009).
Foreign exchange reserve	– Foreign exchange reserves (as % of imports) interacting with disaster damage significant attenuates GDP output decline Noy (2009).
Foreign aid	– Foreign aid does not significantly reduce the consequences of climatic disasters Raddatz (2009). – Foreign aid significantly attenuates GDP output reduction Hochrainer (2009). – Foreign aid interacting with disasters significantly increases GDP growth for non-OECD and democratic countries but its effect is insignificant for all samples (including OECD and non-democratic countries) Ahlerup (2013).
Openness	– Openness does not significantly affect GDP using fixed effects estimates and two-step system GMM estimates but does significantly and positively affect GDP using two-step difference GMM estimates Noy and Nualsri (2007). – Openness significantly and positively affects GDP growth Loayza et al. (2012).
Investment	– Investment as % of GDP significantly affects GDP growth using fixed effects and two-stem system GMM estimates but is insignificant using two-step difference GMM estimates Noy and Nualsri (2007).
Terms of trade gowth rate	– Growth rate of terms of trade significantly and positively impacts GDP growth Loayza et al. (2012).
Remittance	– Inflow of remittances significantly attenuates GDP output reduction Hochrainer (2009).
Social/Human:	
Illiteracy*Disaster	– Countries with higher illiteracy levels interacting with disaster damage will experience higher output decline Noy (2009).
Initial schooling	– Secondary and higher schooling of male population above 15 is not a significant factor affecting GDP growth Noy and Nualsri (2007). – Secondary school enrollment rate is not a significant factor affecting GDP growth Loayza et al. (2012).
Fertility rate	– Fertility rate is not a significant factor affecting GDP growth using the fixed effects estimates but significantly and negatively affects GDP using two-step difference GMM estimates. Evidence is inconclusive using two-step system GMM estimates Noy and Nualsri (2007).
Institutional:	
Institutional Strength*Disaster	– Institutional strength (based on International country risk guide) interacting with disaster damage significantly attenuates output decline Noy (2009).
Government size*Disaster	– Government size (as measured in government consumption as % of GDP) interacting with disaster damage significantly attenuates output decline Noy (2009).
Government size	– Government size (government consumption as % of GDP) does not significantly affect GDP growth Noy and Nualsri (2007). – Government size (government consumption as % of GDP) significantly and negatively affects GDP growth Loayza et al. (2012).
Long-run findings:	
Disaster	
Climatic	– Climatic disasters have a negative and significant impact on per capita GDP (an average long-run effect of −0.6% in which approximately 0.5% is felt in the year of the event) Raddatz (2009). – Climatic disasters as measured in the number of events, and the number of events per land area, have a significant and positive impact on long-term per capita GDP growth Skidmore and Toya (2002). – Climate disasters as measured in the number of events and the number of events per land area has a significant and positive effect on long-term per capita GDP growth Kim (2010).
Geologic	– Geologic disasters have a small and insignificant impact on per capita GDP Raddatz (2009). – Geologic disasters as measured in the number of events and the number of events per land area have a significant and negative impact on long-term per capita GDP growth using data from Davis (1992) but both are insignificant using EM-DAT Skidmore and Toya (2002).

Appendix 2 (*continued*)

Independent variables/ subgroup categories*	Summary of evidence
	– Geologic disasters as measured in the number of events and the number of events per land area have an insignificant impact on long-term per capita GDP growth Kim (2010). – Geologic disasters as measured in the number of events have a positive impact on long-term per capita GDP growth Ahlerup (2013).
Combined disasters	– Disasters as measured in the number of events are insignificant, while events per land is significantly and positively related to long-term per capita GDP growth Kim (2010). – Disasters as measured in the number of events are significantly and positively related to long-term per capita GDP growth Ahlerup (2013).
Vulnerability and Resilience	
Economic:	
Income level	– Initial income is significant and negatively related to long-term per capita GDP growth Skidmore and Toya (2002).
Investment	– Investment as percentage of GDP is significantly and positively related to long-term per capita GDP growth Skidmore and Toya (2002) and Kim (2010).
Trade openness	– Trade openness has significant and positive effect on long-term per capita GDP growth Skidmore and Toya (2002).
Consumption	– Consumption as % of GDP has a significant and positive effect on long-term per capita GDP growth Kim (2010).
Gross domestic savings	– Gross domestic savings as % of GDP has a significant and positive effect on long-term per capita GDP growth Kim (2010).
Social/Human:	
Schooling	– Log of secondary schooling years has a significant and positive effect on long-run per capita GDP growth Skidmore and Toya (2002).
Fertility	– Net fertility rate has a significant and negative impact on long-term per capita GDP growth Skidmore and Toya (2002).
Institutional:	
Government size	– Government consumption as % of GDP has a significant and negative impact on long-term per capita GDP growth Skidmore and Toya (2002). – Government consumption as % of GDP has a significant and positive impact on long-term per capita GDP growth Kim (2010).

Note: The list includes evidence that is not as conclusive due to alternative model specifications and sub-groups adopted for other robustness checks. Please refer to each study for complete details of their findings.

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