The Aftermath of Natural Disasters: Beyond Destruction

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Introduction

Recent catastrophic natural disasters, such as the Indian Ocean tsunami of 2004, and the Haitian earthquake of 2010, have received more international attention than previous disasters, yet our rapidly evolving understanding regarding their relevance to economic development and growth is still in its infancy. Much research in the social sciences, and even more in the natural sciences, has been devoted to increasing our ability to predict disasters and prepare for them. Interestingly, however, the economic research on natural disasters and their consequences is fairly limited. We summarize here the state of this literature and point to questions that we believe need further probing.

Sen (1981), in his seminal economic history of famines, famously observed that starvation is the characteristic of some people not *having* enough food to eat. It is not the characteristic of there *being* not enough food to eat. In Sen's work, the central emphasis is that the costs associated with what we define as natural disasters are largely determined by economic and social forces rather than predetermined by natural processes. Sen's observation suggests that economics is important not only in understanding what happens after a disaster occurs, but rather that the very occurrence of disasters is an economic event.

A recent pertinent example is the devastation that recent earthquakes wrought in Haiti and Chile. The January 2010 earthquake that struck Haiti's densely populated capital, Port-au-Prince, caused significant loss of human life (between 200,000 and 250,000 fatalities), the displacement of more than a million and severe damage to the country's economic infrastructure (estimated over 100 percent of the country's GDP) – see Cavallo, Powell and Becerra (2010). In contrast, the February 2010 earthquake in Chile which was physically stronger and also struck a densely populated area caused many fewer fatalities (less than 500 people killed according to most recent official estimates). And although direct economic damages are expected to be substantial due to the amount of wealth exposed, they are expected to be far less than Haiti's in relation to the size of the economy.[1] Clearly, these dissimilar outcomes originated from different policies, institutional arrangements and economic conditions.

Pelling *et al.* (2002) and ECLAC (2003) introduce a typology of disaster impacts that we adopt here. They distinguish between direct and indirect damages. Direct damages are the damage to fixed assets and capital (including inventories), damages to raw materials and extractable natural resources, and of course mortality and morbidity that are a direct consequence of the natural phenomenon. Indirect damages refer to the economic activity, in particular the production of goods and services, that will not take place following the disaster and because of it. These indirect damages may be caused by the direct damages to physical infrastructure, or because reconstruction pulls resources away from production. These indirect damages also include the additional costs that are incurred because of the need to use alternative and potentially inferior means of production and/or distribution for the provision of normal goods and services. At the household level, these indirect costs also include the loss of income resulting from the non-provision of goods and services or

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[1] Chile's vast experience with prior earthquakes, its prudent macroeconomic policies in the last two decades and its copper sovereign wealth fund have all been used to motivate predictions about a speedy recovery in the aftermath of the earthquake (Barrioneuvo 2010).

from the destruction of previously used means of production. These costs can be accounted for in the aggregate by examining the overall performance of the economy, as measured through the most relevant macroeconomic variables. They can also be further divided, following the standard distinction in macroeconomics, between the short run (up to several years) and the long run (at least five years but sometimes also measured in decades). We use this distinction in the discussion that follows.

The second section begins with a brief review of the main data sources used in this largely empirical literature. The third section discusses the determinants of the direct effects, while the fourth section examines the indirect effects. The fifth section focuses on policy, while the sixth section describes several case studies of specific disasters and the insights gained from them. The final section 7 summarizes and points to several significant gaps in this literature.

Data on disasters

Almost all the empirical work we survey here relies on the publicly available Emergency Events Database (EM-DAT) maintained by the Center for Research on the Epidemiology of Disasters (CRED) at the Catholic University of Louvain, Belgium (http://emdat-be/). The database is compiled from various sources, including UN agencies, non-governmental organizations, insurance companies, research institutions and press agencies.

EM-DAT defines a disaster as a natural situation or event which overwhelms local capacity and/or necessitates a request for external assistance. For a disaster to be entered into the EM-DAT database, at least one of the following criteria must be met: (a) ten or more people are reported killed; (b) 100 people are reported affected; (c) a state of emergency is declared; or (d) a call for international assistance is issued. Disasters can be hydro-meteorological including floods, wave surges, storms, droughts, landslides and avalanches; geophysical including earthquakes, tsunamis and volcanic eruptions; and biological covering epidemics and insect infestations (these are much more infrequent in this database).

The data report the number of people killed, the number of people affected and the dollar amount of direct damages in each disaster. The amount of material damage reported in the database consists only of direct damages (e.g. damage to infrastructure, crops and housing). An alternative but similar source that is less extensive, and only parts of which are publicly available, is the Munich Re dataset at http://mrnathan.munichre.com/. A similar data collection effort with similar coverage but more limited access is maintained by another reinsurer, Swiss Re. For an analytical review of selected data sets on natural disasters, see Tschoegl *et al.* (2006).

A few papers use other data sources. Most notable are those that aim to estimate the impact of storms/hurricanes. These papers use data on storm intensity, typically measured by wind speed or storm radius that are taken from the US National Oceanic and Atmospheric Administration (NOAA) and the Pielke *et al.* (2008) database.

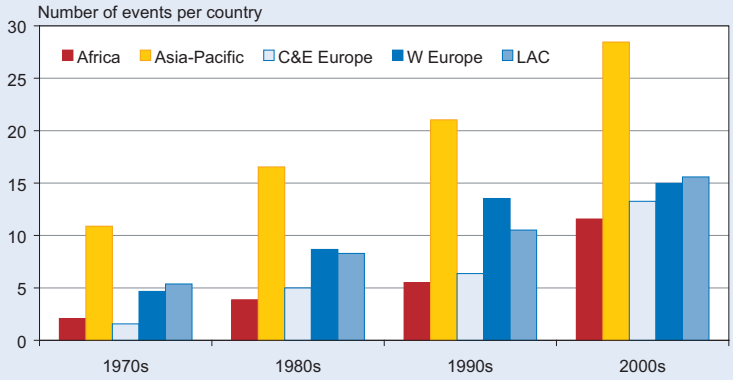
Before reviewing the evidence on the impacts of natural disasters, it is useful to describe the stylized facts. First, natural disasters, as defined in the EM-DAT database, are fairly common events and their reported incidence has been growing over time. Figure 1 plots the average number of natural events (including hydro-meteorological and geophysical events) per country over the span of the last four decades. The figure shows that the incidence of disasters has been growing over time everywhere in the world. For example, in the Asia-Pacific region which is the region with the most events, the incidence has grown from an average of 11 events per country in the 1970s to over 28 events in the 2000s.[2] In other regions, while the increase is less dramatic, the trend is similar. However, these patterns appear to be driven to some extent by improved recording of milder events, rather than by an increase in the frequency of occurrence. Furthermore, truly large events – i.e. conceivably more catastrophic – are rarer. Both of these facts are shown in Figure 2, where the sample is restricted to large events only, and where 'large' is defined in relation to the world mean of direct damage caused by natural events.[3]

As is evident from the figure, there is no time trend for the subset of large events in any region. Moreover, the frequency of occurrence of 'large' disasters is significantly smaller than for all events. For example, while there are more than 28 events

[2] The numbers corresponding to the decade of 2000 were adjusted to account for the fact that there is one fewer year of reported data in this decade.
[3] A large disaster occurs when its incidence, measured in terms of people killed as a share of population, is greater than the world pooled mean for the entire sample period.

Figure 1

INCIDENCE OF NATURAL DISASTERS BY REGION 1970–2008
Total number of disasters by region
Hidro-meteorological and geological



Note: 2000s figures were adjusted to account for the fewer number of years in the decade.
Source: Authors' calculations based on data from EM-DAT database.

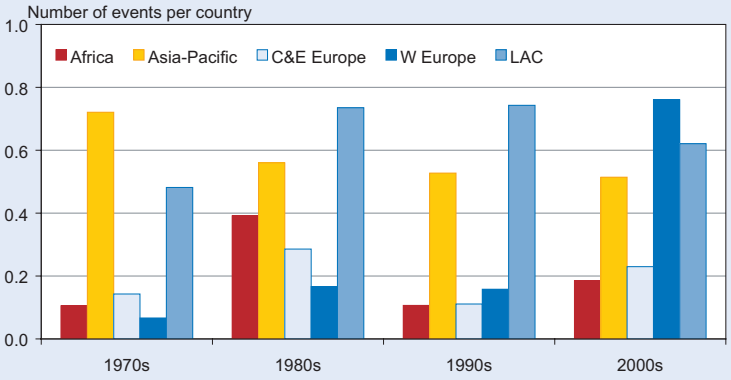
per country on average in the Asia-Pacific region in the 2000s, the frequency of occurrence of large events is only 0.5 episodes per country. This suggests that the threshold for what constitutes a disaster (and hence gets recorded in the dataset) is quite low.

The overwhelming majority of people affected and killed by natural disasters reside in developing countries, particularly in the Asia-Pacific region. Figures 3 and 4 show that 96 percent of the people killed and 99 percent of the people affected by natural disasters over the period 1970–2008 were in the Asia-Pacific region, Latin America and the Caribbean, or Africa, whereas the combined population share of these three regions is approximately 75 percent of the world population. Since the 1970s, and excluding the most recent 2009–2010 events, almost three million people were reportedly killed by natural disasters in the three most vulnerable regions.

In summary, natural events are frequent although 'large' events – the ones that would typically be considered catastrophic – are rarer. The direct costs associated with these events are huge, and developing countries bear the lion's share of the burden, in terms of both casualties and direct economic damages.

Figure 2

INCIDENCE OF 'LARGE' NATURAL DISASTERS BY REGION 1970–2008
Total number of disasters by region
Over the mean – hidro-meteorological and geological



Note: 2000s figures were adjusted to account for the fewer number of years in the decade.
Source: Authors' calculations based on data from EM-DAT database.

Determinants of initial disaster costs

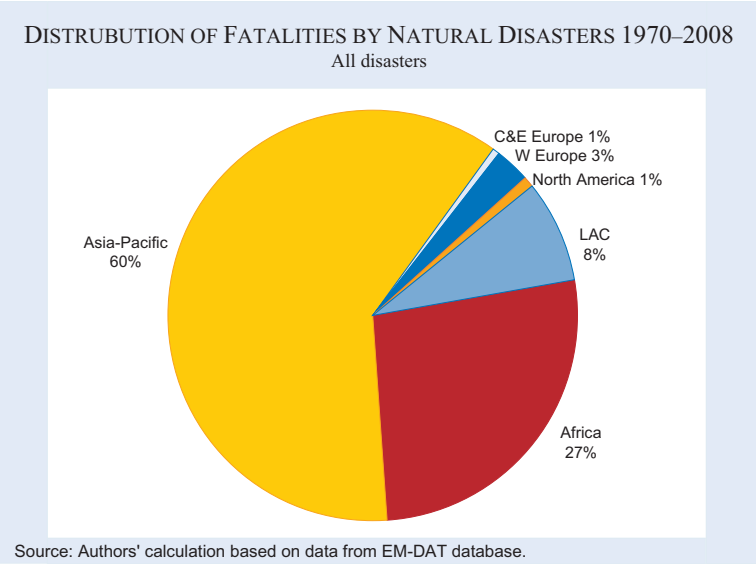
A spate of papers in the last several years has attempted to understand the determinants of the initial direct costs of disasters. When evaluating the determinants of disasters, most papers estimate a model of the form:

$$DIS_{it} = \alpha + \beta \mathbf{X}_{it} + \varepsilon_{it} \quad . \qquad (1)$$

where DIS_{it} is a measure of direct damages of a disaster in country i and time t; using measures of primary initial damage such as mortality, morbidity or capital losses. $\mathbf{X}_{it}$ is a vector of control variables of interest with each paper distinguishing different independent variables; typically $\mathbf{X}_{it}$ will include a measure of the disaster magnitude (i.e. Richter scale for earthquakes or wind speed for hurricanes) and variables that capture the 'vulnerability' of the country to disasters (i.e. the conditions which increase the susceptibility of a country to the impact of natural hazards). Instead of estimating these panels, several papers aggregate the data across time and estimate cross sections of country observations.

One of the conditions that may increase a country's susceptibility to the impact of natural disas-

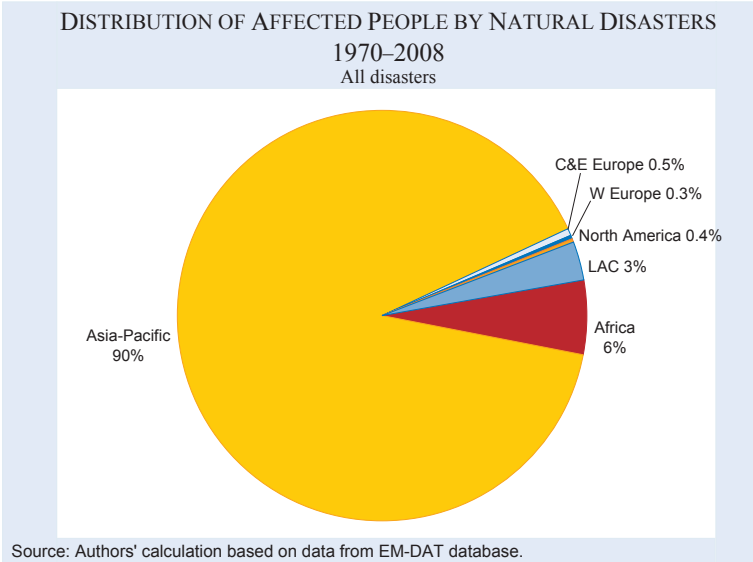
Figure 3



Source: Authors' calculation based on data from EM-DAT database.

ters is its level of economic development. Kahn (2005) estimates a version of equation (1) and concludes that while richer countries do not experience fewer or less severe natural disasters, their death toll is substantially lower. In 1990, a poor country (per capita GDP < 2000 US dollars) typically experienced 9.4 deaths per million people per year, while a richer country (per capita GDP > 14,000 US dollars) would have had only 1.8 deaths. This difference is most likely due to the greater amount of resources spent on prevention efforts and legal enforcement of mitigation rules (e.g. building codes). In particular, some of the policy interventions likely to ameliorate disaster impact, including land-use regulations, building codes and engineering interventions,

Figure 4



Source: Authors' calculation based on data from EM-DAT database.

are rare in less developed countries (see, for example, Freeman *et al.* 2003).

Notwithstanding this, Kellenberg and Mobarak (2008) suggest a more nuanced, nonlinear relationship between economic development and vulnerability to natural disasters, with risk initially increasing with higher incomes as a result of changing behaviors, such as residents locating to more desirable but more dangerous sites near coasts and floodplains. Sadowski and Sutter (2005) provide some confirmation for this view by examining hurricanes in the United States and the ways in which better preparedness leads to higher residential coastal concentrations (where the risk from hurricane-associated wave surges is actually higher).

Other papers focus on the political and institutional factors that affect disaster impact. A consistent finding of several studies (i.e. Kahn 2005; Skidmore and Toya 2007; Plümper and Neumayer 2009; Raschky 2008) is that better institutions – understood, for instance, as more stable democratic regimes or greater security of property rights – reduce disaster impact. Anbarci *et al.* (2005) elaborate on the political economy of disaster prevention. They conclude that inequality is important as a determinant of prevention efforts: more unequal societies tend to have fewer resources spent on prevention, as they are unable to resolve the collective action problem of implementing preventive and mitigating measures. In a similar vein, Besley and Burgess (2002) observe that flood impacts in India are negatively correlated with newspaper distribution; they attribute this effect to the fact that when circulation is higher, politicians are more accountable and the government is more active in both preventing and mitigating the impacts of disasters. Eisensee and Strömberg (2007) reach similar conclu-

sions regarding the response of US disaster aid to media reports.

Healy and Malhotra (2009) add to this literature by identifying the lack of political accountability for elected public officials in the United States as an explanation for inefficient allocation decisions. Voters reward candidates for post-disaster aid but not for well-funded prevention. Thus, the public sector under-invests in preventing these catastrophic events, but readily spends on post-disaster reconstruction and aid.

In summary, thinking of natural disasters as economic phenomena and not as purely exogenous events has led researchers to seek to explain the fundamental structural determinants of the direct damages incurred from disasters. While the damage caused by disasters is naturally related to the physical intensity of the event, the literature has identified a series of economic, social, and political characteristics that also affect vulnerability. A by-product of this analysis, of course, is that these characteristics are therefore potentially amenable to policy action.

Cross-country studies of indirect impacts

A disaster's initial impact causes mortality, morbidity and loss of physical infrastructure (residential housing, roads, telecommunication and electricity networks as well as other infrastructure). These initial impacts are followed by consequent impacts on the economy (in terms of income, employment, sectoral composition of production, inflation, etc.). Macroeconomics generally distinguishes between the short run (usually up to three years) and the long run (anything beyond five years is typically considered the long run). In what follows we summarize the literature on the indirect economic effects of natural disasters.

When evaluating the determinants of these consequent impacts of disasters in a regression framework, most recent papers estimate a model of the form:

$$Y_{it} = \alpha + \beta \mathbf{X}_{it} + \gamma DIS_{it} + \varepsilon_{it} \ . \qquad (2)$$

where Y_{it} is the measured consequent impact of interest (e.g. per capita GDP). DIS_{it} is a measure of the disaster's immediate impact on country i at time t; it is sometimes a binary indicator of disaster occurrence and sometimes a measure of the disaster magnitude – either using physical criteria such as wind-speed or earthquake magnitude or using measures of primary initial damage such as mortality, morbidity or capital losses. $\mathbf{X}_{it}$ is a vector of control variables that potentially affect Y_{it}.

In order to facilitate investigations into the interaction of the initial disaster impact with country-specific conditions, equations such as:

$$Y_{it} = \alpha + \beta \mathbf{X}_{it} + \gamma DIS_{it} + \delta DIS_{it} \cdot \mathbf{V}_{it} + \vartheta \mathbf{V}_{it} + \varepsilon_{it} \qquad (3)$$

are used, where the $\mathbf{V}_{it}$ variables are the hypothesized interactions of disaster impact with macroeconomic, institutional or even demographic or geographic characteristics. In these specifications, the coefficients of interest are typically γ and the vector δ.

Noy (2009) estimates a version of equation (3) and finds that natural disasters have an adverse short-run impact on output dynamics. In addition he describes some of the structural and institutional details that make this negative effect worse. He concludes that countries with a higher literacy rate, better institutions, higher per capita income, higher degree of openness to trade, higher levels of government spending, more foreign exchange reserves, and higher levels of domestic credit but with less open capital accounts are better able to withstand the initial disaster shock and prevent further spillovers. Subsequently, Raddatz (2009) extends the investigation to the impact of various types of natural disasters on countries in different income groups. He concludes that smaller and poorer states are more vulnerable, especially to climatic events, and that most of the output cost of climatic events occurs during the year of the disaster. His evidence also suggests that, historically, aid flows have done little to attenuate the output consequences of climatic disasters. More recent work adds more detail by differentiating between different types of events and different economic sectors (e.g. Hochrainer 2009; Loayza *et al.* 2009).

Several papers pursue similar investigations, but instead of relying on cross-country panels, they rely on more detailed panels at the firm, county, region, or the state level. Strobl (2008) uses differences in hurricane impact on coastal counties in the United States; Noy and Vu (2009) use provincial disaster data from Vietnam; and Leiter *et al.* (2009) uses European firm-level data.

In summary, the emerging consensus in the literature is that natural disasters have, on average, a negative impact on short-term economic growth. Yet, the channels that are responsible for this economic slowdown have not been described methodically at all.

In investigations into the long-term impact of natural disasters, Skidmore and Toya (2002), and Noy and Nualsri (2007) reach diametrically opposite conclusions, with the former identifying expansionary and the latter contractionary disaster effects. More recently, Jaramillo (2009) finds qualified support for the Noy and Nualsri (2007) conclusion. Skidmore and Toya (2002) explain their somewhat counterintuitive finding by suggesting that disasters may be speeding up the Schumpeterian 'creative destruction' process that is at the heart of the development of market economies. Cuaresma *et al.* (2008) attempt to investigate this creative destruction hypothesis empirically by closely examining the evolution of R&D from foreign origin and how it is affected by catastrophic risk. They conclude that the creative destruction dynamic most likely only occurs in countries with high per capita income. For developing countries, disaster occurrence is associated with less knowledge spillover and a reduction in the amount of new technology being introduced. Hallegatte and Dumas (2009) critically examine the creative destruction hypothesis using a calibrated endogenous growth model. They conclude that disasters are never positive economic events and find that large disasters that overwhelm local reconstruction capacity may actually lead to poverty traps.

When compared to the short-run research, the literature on the long-run effects of natural disasters is scant and its results inconclusive. Cavallo, Galiani, Noy and Pantano (2010) provide the most recent attempt to bridge that gap. They implement a new methodological approach based on a comparative event study approach. The idea is to construct an appropriate counterfactual – i.e. what would have happened to the path of gross domestic product (GDP) of the affected country in the absence of a natural disaster and to assess the disaster's impact by comparing the counterfactual to the actual path observed. The paper concludes that unless a natural disaster triggers a radical institutional change; it is unlikely to affect economic growth in the long run.

Almost all existing research focuses on domestic production (GDP) or on incomes; other impacts of disasters have been under-investigated. Rodriguez-Oreggia *et al.* (2009) and Mechler (2009) innovate by examining poverty and human development (the World Bank's Human Development Index, HDI) and consumption, respectively, instead of the standard growth variables. The first paper shows a significant increase in poverty and a decline in the HDI in disaster-affected municipalities in Mexico; poverty increases by 1.5–3.6 percentage points. The second paper finds a small decrease in household consumption for low-income countries hit by disasters.

The fiscal impact of natural disasters has also been under-investigated. On the expenditure side, publicly financed reconstruction costs may be very different than the original magnitude of destruction of older capital that occurred (Fengler *et al.* 2008). On the revenue side of the fiscal ledger, the impact of disasters on tax and other public revenue sources has also seldom been quantitatively examined. Using panel VAR methodology, Noy and Nualsri (2008) estimate the fiscal dynamics likely in an 'average' disaster; however, they acknowledge that the impacts of disasters on revenue and spending depend on the country-specific macroeconomic dynamics occurring following the disaster shock, the unique structure of revenue sources (income taxes, consumption taxes, custom dues, etc.), and large expenditures.[4] Borensztein *et al.* (2009) utilize data from Belize to estimate in a calibrated model the likely fiscal insurance needs of a government. Barnichon (2008) calculates the optimal amount of international reserves for a country facing external disaster shocks using a similar methodology.[5] Yang (2008) and Bluedorn (2005) investigate the evolution of capital flows following disasters, and both conclude that disasters generate some inflows (mostly international aid but also other types of flows like remittances).

Case studies of disaster impacts

Several research projects have examined the economic impact of specific disaster events. Examples are the 1995 Kobe earthquake in Japan (Horwich 2000), the 1999 earthquake in Turkey (Selcuk and Yeldan 2001) and hurricane Katrina in 2005 (Hallegatte 2008; Vigdor 2008). Most of these are descriptive, though some also construct calibrated models that simulate the dynamics of the economy

[4] Lis and Nickel (2009) examine similar questions.
[5] See also Cárdenas *et al.* (2007) and Mechler *et al.* (2009).

after it is hit by the disaster and are therefore able to tentatively evaluate various policy responses. More recently, Cavallo, Powell and Becerra (2010) estimate Haiti's economic damage to fixed assets, extractable natural resources and raw materials in the aftermath of the earthquake that struck the Caribbean country on 12 January 2010 – by far the most catastrophic natural disaster in modern records in terms of fatalities (relative to the country's population).

These analyses were typically written not very long after the event considered. In contrast, Coffman and Noy (2009) investigate the long-term impact of a 1992 hurricane on the economy of a Hawaiian island. In this case, the long horizon available, the unexpectedness of the event, and the existence of an ideal control group subjected to almost identical conditions but not the hurricane itself, enables them to argue that in spite of massive transfers, it took nearly seven years for the island's economy to return to its pre-hurricane per capita income level. The hurricane also resulted in an out-migration of residents from which the island's population has not fully recovered. The island permanently 'lost' about 15 percent of its population as a result of the hurricane, even though very few deaths were associated with the storm.

Policies and disasters

Perrow (2007), in a recent book on reducing catastrophic vulnerabilities in the United States, argues that public policy should focus on the need to 'shrink' the targets: lower population concentration in vulnerable (especially coastal) areas, and lower concentration of utilities and other infrastructure in disaster-prone locations. This advice stems from the awareness that more *ex-post* assistance to damaged communities generates a 'Samaritan's dilemma', i.e. an increase in risk-taking and a reluctance to purchase insurance when taking into account the help that is likely to be provided should a disaster strike.[6] However, apart from these *ex-ante* 'shrink-the-target' policies, many other *ex-ante* and *ex-post* policies that can alleviate or worsen the economic impact of disasters will necessarily be weighed before and after any large event.

Besides policies that can reduce initial disaster damage, policies that can reduce the longer-term economic damage that disasters can wreak should also be contemplated. We have already observed that large disasters typically lead to reduced production and incomes, even if the exact distribution of these effects and their causes are not yet clear. Yet, as Freeman *et al.* (2003) observe, some of the other likely macroeconomic impacts of disasters may be a deteriorating trade balance, downward pressure on the exchange rate, and upward pressure on prices. How to deal with these likely dynamics is a policy question that also needs to be asked.

Ex-ante insurance vs. ex-post disaster financing

Kunreuther and Pauly (2009) survey some of the problems associated with *ex-ante* insurance coverage for large natural events: uncertainty with regard to the magnitude of potential loses, highly correlated risk among the insured, moral hazard that leads to excessive risk taking by the insured, and an adverse selection of insured parties caused by imperfect information. Their work also distinguishes between unknown disasters (those for which the likelihood and the distribution of probable magnitudes are at least partially known) and the unknowable (those for which no information is available). Even though natural disasters are typically not unknowable, these problems still clearly lead to under-insurance. In all recent disasters, even in ones that happened in heavily insured countries like the United States, only a relatively small portion of actual damages was insured. For example, hurricane Katrina led to insurance claims totaling 46.3 billion US dollars; while the estimated damage of the storm was 158.2 billion US dollars.[7]

Insurance for the public sector, in order to secure the availability of reconstruction expenditures, is also an important policy question. There is broad consensus on the need to design fiscal management policies to resist the stress caused by the occurrence of disasters. Freeman *et al.* (2003) consider ways to create the necessary fiscal space to deal with catastrophic risk. Among various alternatives, they advocate treating natural disasters as a contingent liability for the national government (although they are skeptical about this suggestion's practical feasibility, par-

[6] This is similar to the moral hazard problem common in insurance markets. Raschky and Weck-Hannemann (2007) define it as 'charity hazard'.

[7] Katrina insurance claim data are from Kunreuther and Pauly (2009), while the figure for total damages is taken from EM-DAT. The Congressional Budget Office estimates 70 to 130 billion US dollars as direct damages (excluding the cost of clean-up and repairs) for hurricanes Katrina and Rita.

ticularly in low-income countries). A more substantive initiative would be to implement an annual budgetary allocation to provide for natural disaster expenditure when needed. Mexico's FONDEN *(Fondo Nacional de Desastres Naturales)* provides this kind of fiscal provisioning against the risk of natural disasters. But these measures, while prudent, amount to forms of self-insurance, which may be very costly in the case of an economy with substantial credit constraints.

Borensztein *et al.* (2009) argue that, in the case of developing countries exposed to large natural disasters, insurance – or debt contracts with insurance-like features – provides an attractive alternative to self-insurance. For example, they examine the vulnerability of Belize's public finance to the occurrence of hurricanes and the potential impact of insurance instruments in reducing that vulnerability. Through numerical simulations they show that catastrophic risk insurance significantly improves Belize's debt sustainability.

Implementing disaster insurance in developing countries, however, faces three types of obstacles: paucity of markets, political resistance and inadequate institutional framework. For a number of reasons, markets have traditionally been insufficiently developed or simply nonexistent (more on this below). More recently, however, advances such as the development of parametric insurance policies have expanded the availability of coverage for countries and households (Cárdenas 2008).[8]

Political reluctance to engage in insurance purchase derives from the fact that there is little short-run benefit to be gained from entering into insurance contracts. Insurance involves costs today and a possible payoff in the undetermined future, when the government may have already changed hands. In addition to these incentive problems, disasters are widely considered as 'acts of God' (or natural phenomena), and politicians are not often blamed for their occurrence. Politicians and policy-makers therefore face very weak incentives for adopting relatively complex measures, such as purchasing market insurance, to offset some of the costs. Healy and Malhotra (2009) present evidence to support these conjectures even for the transparent and fairly stable political system of the United States. However, since governments are typically held accountable for their response to disasters, they have strong incentives to massively invest in *ex-post* assistance.

Of the three obstacles that deter the development of a catastrophic risk insurance market, the one related to market unavailability has been the most studied. The consensus is that governments in countries that are vulnerable to natural disasters appear to have only a limited set of options available to insure public finances against those risks, although progress is slowly being made. Hofman and Brukoff (2006), Cárdenas (2008), Andersen (2007), and Miller and Keipi (2005) survey some recent initiatives in this regard. The risk profile of catastrophe insurance claims differs from that of other insurance products. A company providing car insurance can easily diversify if it has many clients, since the volume of claims would then be highly predictable. In contrast, natural disasters are low-probability events that can cause extremely large losses when they occur and are thus not easily diversifiable in the same way as car insurance. This low level of diversification increases the cost of insurance. Its price is very volatile and fluctuates sharply every time there is a major catastrophic event that depletes reserves. Primary insurers need to transfer a considerable share of their catastrophe exposure to large reinsurers, and this increased reliance on reinsurers increases the cost of primary insurance, reducing its attractiveness and scope.

Private capital markets offer some complementary alternatives that may increase the availability of financing options as they continue to develop. The first capital market instrument linked to catastrophe risk ('cat bonds') was introduced in 1994 as a means for reinsurers to transfer some of their own risks to capital markets. Since then, their success has prompted governments and international institutions to explore their use as a mean of shielding government budgets from the impact of natural disasters (Andersen 2007). A catastrophe bond is a tradable instrument that facilitates the transfer of the risk of a catastrophic event to capital markets. In May 2006 and again in October 2009, the Mexican government obtained earthquake and hurricane insurance by

[8] Instead of basing payments on an estimate of the damage suffered, parametric insurance contracts establish the payout as a function of the occurrence or intensity of certain natural phenomenon, as determined by a specialized agency such as the US National Hurricane Center. In this way, the transaction costs and uncertainty associated with insurance payments are considerably reduced. There is no need to verify and estimate damages, and no potential disagreement or litigation about the payouts. Moreover, the country has immediate access to the resources when the disaster takes place.

means of cat bonds and a direct purchase of coverage from international reinsurers.[9]

While these are encouraging developments, the private catastrophic risk market is still in its infancy. And even if the supply side of risk financing instruments becomes fully developed, important questions remain unanswered. For example: what is the optimal level of insurance that countries should purchase given the cost of insurance, the menu of alternative financing options (self-insurance, *ex-post* debt accumulation, foreign aid, etc.), and country characteristics (access to external credit, macroeconomic environment, institutional quality, etc.)? What is the appropriate institutional set-up that ensures the proper functioning of insurance schemes while minimizing moral hazard and adverse selection? What is the appropriate role of the government *vis-à-vis* the private sector in catastrophe insurance markets? These are still open questions that warrant further analysis.

Monetary and exchange rate policy

There has been very little research on the monetary aspects of disaster dynamics. As far as we are aware, even elementary questions such as, for example, the inflationary impact of a large disaster and the aid surge in its aftermath, have not been carefully examined. Open-economy questions, such as the impact of disasters on exchange rates (real or nominal) or the terms of trade have also not been examined empirically or analytically.

Keen and Pakko (2007) construct a dynamic stochastic general equilibrium model calibrated for the US economy and the impact of Katrina, and evaluate the optimal response of monetary policy to a Katrina-like shock. They find, intriguingly, given public discussion and market perceptions at the time, that optimal monetary policy design should involve raising interest rates following a large disaster. They show that this result holds for both a Taylor-rule setting of interest rates, for optimal policy setting that replicates the efficient markets solution, and when the model includes nominal rigidities in both prices and wages. Keen and Pakko (2007) argue that this result arises because the anti-inflationary justification for the contractionary policy will trump any desire to temporarily expand output.

In possibly the only empirical paper on exchange rates and disasters, Ramcharan (2007) examines exchange rate policy and its affect on the damage inflicted by disasters. He finds consistent evidence that flexible exchange rate regimes provide a cushion that ameliorates the disaster's negative impact on growth.

Conclusions and remaining questions

The economics of natural disasters are important. In order to facilitate further necessary research on this topic, we summarized the state of this literature. We believe that large gaps in this literature remain. The EM-DAT, the only internationally comparable and available data on disasters, collects only limited information on conceivably too many events.[10] A more detailed accounting of the physical destruction wrought by large disasters and their human toll may prove to be very useful. We would especially like to be able to distinguish among residential damage, crop devastation, infrastructure damage and destruction of manufacturing facilities in order to better address many of the questions that remain unanswered.

While the literature we reviewed examines the short- and long-run effects of disasters and provides detailed, if inconclusive, accounting of post-disaster dynamics, it does not provide any description of the channels through which disasters cause these effects. An understanding of the channels of causality, in both the short and the long run, will surely enable more informed *ex-post* policymaking and possibly better *ex-ante* preparation and mitigation.

We have presented some provisional evidence that the extent of adverse impact is related to the ability to mobilize significant funding for reconstruction. We have also shown that poorer countries are likely to suffer more from future disasters, but these countries are also unlikely to be able to adopt the counter-cyclical fiscal policies that can pay for reconstruction. This constraint will make disasters'

[9] The cat bond issued in 2006 (for a total of 150 million US dollars in coverage) was the first to cover disaster risk in Latin America. The Mexican government has followed this initiative and introduced a new cat bond issue in October 2009 sponsored by FONDEN. This USD 290 million three year cat bond provides cover for earthquakes on the Pacific coast (140 million US dollars), Pacific hurricanes (100 million US dollars) and Atlantic hurricanes (50 million US dollars). Coverage will last for three years.

[10] Since the threshold used to determine what constitutes a disaster is quite lenient, the dataset contains limited information on a large variety of events.

adverse consequences more severe in poorer developing countries. A better-targeted reconstruction that is informed by the identified channels of transmission can potentially alleviate some of these resource constraints.

A further significant lacuna in the current state of our knowledge is the absence of any agreement regarding the long-run effects of these disasters. Whether these disagreements have any substantial real relevance to policy decisions can only be assessed when the channels of transmission and propagation for these effects become more evident.

We have not reviewed the micro-development literature that has been examining the ways in which households (typically rural households) deal with sudden disaster events (e.g. Townsend 1994; Udry 1994; Dercon 2004). Whether these shed light on the channels of transmission is a possibility that needs to be further explored. Nor have we reviewed the literature on aid allocations following disasters and their impact. This small literature was recently surveyed by Strömberg (2007) who also provides stylized facts on who gives relief, how much is given and who receives it.

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