Natural natural disasters and economic disruption

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Abstract

The cost of natural calamities is not limited to direct capital losses. Economies in the wake of severe shocks experience important slowdowns. I construct an exhaustive dataset of objective measures on cyclones and earthquakes worldwide between 1980 and 2006 and estimate the amplitude of indirect economic losses in the aftermath of these catastrophes. Declared damages accounting for 1% of GDP are associated with a slowdown of .05 to .06 points of GDP growth. The economic slack piles up to .4 points of GDP when I instrument by actual exposure to alleviate censorship issues and declaration biases. This output loss is superior to what would suggest a model of labor frictions and capital losses and points to large business disruptions.

Keywords: Natural disasters, economic disruption, declaration biases.

JEL classification: O13, Q51, Q54

The impact of natural disasters on economies is often under-estimated. The reason is that reports on economic damages following a severe shock focus on direct capital losses, leaving aside the indirect effects on domestic production. Few economic studies have evaluated the amplitude of propagation of initial tremors to the rest of the economy. Two recent contributions (Noy [2009], Strobl [2011*b*]) have found a negative and significant effect of natural disasters on the immediate output. This paper complements these studies by (i) providing a systematic estimation of

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these effects based on a unique dataset, (ii) proposing a simple quantitative exercise to capture the nature of economic losses.

Relying on an exhaustive catalog of sudden disasters (cyclones and earthquakes) for which I have precise and objective measures, I estimate the amplitude of economic disruption after the realizations of large direct losses. I find economic spillovers far larger than established in previous studies for cyclones. Direct losses of $ 1 following cyclones echo on economic activity with output losses of 40 cents. On the one hand, this amplitude is surprisingly high. Assuming capital losses only, even a model with perfectly rigid labor markets would suggest a lower production slack. Business disruption is the unobserved component which might explain the gap existing between the observed repercussions and a reasonable worst-case scenario with capital losses only. On the other hand, the negative spillover seems to fade away one year later on average, with economies growing in parallel with the pre-disaster growth path. While this study depicts seemingly large but non-persistent events for cyclones, it points to non significant slowdowns following earthquakes. The differences found between the two types of catastrophes seem to be due to differential impacts rather than differences in the quality of reports.

Note that I do not investigate the channels of propagation through the economy, this average picture neglects differences of recovery across economies[1]. Taking into account the differential impacts on different sectors of the economy might help attenuate the discrepancy found between cyclones and earthquakes.

The literature on macroeconomic consequences of natural disasters has roughly followed two leads. While Albala-Bertrand [1993], Noy [2009] and Strobl [2011*b*] have tried to estimate directly the effect of calamities on aggregate production, other papers have tried to isolate some components of the economy and exhibit particular

[1] As highlighted in Noy [2009], financial institutions might alleviate the pressure imposed on the economy by large capital losses and offset the potential negative spillovers. The capacity to allocate efficiently labor and capital to affected zones and sectors should curb economic losses and impede the propagation to other parts of the economy. Naturally, the potential disruption of economic activity is also related to the capacity to mobilize resources from international assistance. Isolated economies with limited financial sectors might not be able to restore quickly a competitive economic environment.

channels of transmission[2]. Overall, it seems difficult to extract a clear trend for the aggregate domestic production. Nevertheless, contradicting a seminal and mostly descriptive paper (Albala-Bertrand [1993]), Noy [2009], Raddatz [2009] and Strobl [2011*b*] have found a negative and significant effect of large natural shocks on ongoing domestic production. Countries with weak financial institutions and restricted access to external funding are particularly prone to economic slowdowns.

Except Strobl [2011*b*], these articles on natural disasters in the economic literature have relied on reported losses rather than objective measures to assess how an economy might be affected by a catastrophe. Economic damages related to natural catastrophes are usually estimations provided by government officials or NGOs. These reports suffer from important biases. In particular, relying on declarations contributes to a systematic underestimation of economic losses in countries where governments do not turn to international assistance - deliberately or not. This article alleviates this stumbling block by (i) refining the choice of experiments - shocks will be sudden - and (ii) by instrumenting reports by objective indicators of exposure.

Why does a shock need to be sudden? Natural disasters are not always instantaneous shocks and direct losses are partly associated with the access to international assistance for the case of epidemics or droughts. Relief and post-shock management have a large influence on the level of damages for long-lasting events. In short, the exogenous component of losses might be very small in the case of non-sudden catastrophes.

Why do we need objective indicators? Capital losses are not completely verifiable. This feature is extremely important and explains the absence of formal private and public insurance in most countries. As such, reports might be biased downward (when not censored) or upward depending on the returns expected from signaling

[2]Gassebner, Keck and Teh [2006] establishes that spillovers on trade are far larger for non-democratic countries, pointing out a potential role for governance. Similarly, Kahn [2005] find a positive correlation between human losses and the quality of governance. Focusing partly on Caribbean countries, Rasmussen [2004] documents significant fiscal and external balance deterioration in the aftermath of cyclones. Finally, Skidmore and Toya [2002] relates the frequency of natural disasters a country might experience to rates of human capital accumulation and TFP growth. Natural disasters increase returns to human capital relatively to returns to physical capital. More subtly, they could favor the adoption of new technologies by wiping out existing capital stocks.

an important vulnerability or a good recovery. These biases are usually not tackled in the literature[3].

To my knowledge, this paper is the first paper of this literature trying to identify the amplitude of economic disruption using an exhaustive and worldwide dataset of large and sudden catastrophes - earthquakes and wind-based events. This paper also makes methodological contributions by establishing the predictive power of such measures.

Section I. presents the estimation strategy and describe the data sources. Section II. describes the measures of objective exposure to natural disasters. Section III. documents the estimations of income losses. Finally, the results on the aftermath of natural disasters are discussed and compared with other shocks in section IV..

I. Estimation strategy and data sources

A. Estimation strategy

To assess the amplitude of the economic slowdown following a year t for a country i exposed to direct losses D_t^i , I investigate the relationship between the level of annual direct damages $d_t^i = D_t^i/Y_t^i$ normalized by GDP, and the indirect downturn in domestic production measured by the output growth during the period t, $y_t^i = (Y_t^i - Y_{t-1}^i)/Y_{t-1}^i$. I will assume in this regard that direct damages are losses of productive capital. Those losses should alsoencompass the destruction of unproductive units of capital and supposedly a potential freeze of the economy. In practice, business disruptions are reported for very few large catastrophes. The production sector of the economy has a standard production technology $Y = AK^\alpha L^{1-\alpha}$ using capital K and labor L as inputs with returns r and w. Assuming that losses are small relatively to the entire capital stock of the economy, this equation can be log-linearized between

[3]For instance, Kahn [2005] and Noy [2009] find a positive correlation between human and economic losses and the quality of governance. This might reflect that good governance matters. Or this could be driven by a systematic over-estimation by government officials of poorly institutionalized countries.

t and $t-1$,

$$y_t^i = \frac{dY_{t,t-1}}{Y_{t-1}} = \frac{dA_{t,t-1}}{A_{t-1}} + \alpha\frac{dK_{t,t-1}}{K_{t-1}} + (1-\alpha)\frac{dL_{t,t-1}}{L_{t-1}}$$

Note that, under the assumption that d_t^i only stands for capital losses, $dK_{t,t-1}/K_{t-1} = -\left(d_t^i - E\left[d_t^i\right]\right)Y_{t-1}/K_{t-1} - E\left[d_t^i\right]Y_{t-1}/K_{t-1}$ where $E\left[d_t^i\right]$ is the expected depreciation of capital and d_t^i the actual depreciation. Imposing that the rest of the economy is left unaffected, the previous equation then becomes

$$y_t^i = -\alpha Y_{t-1}/K_{t-1}\left(d_t^i - E\left[d_t^i\right]\right) - E\left[d_t^i\right]Y_{t-1}/K_{t-1} = -r_{t-1}\left(d_t^i - E\left[d_t^i\right]\right) - E\left[d_t^i\right]Y_{t-1}/K_{t-1}$$

where r_{t-1} is the marginal productivity of capital. The empirical counterpart of this equation will be:

$$y_t^i = \beta_d\left(d_t^i - E\left[d_t^i\right]\right) + \tilde{y}_t^i + \varepsilon_t^i$$

The counterfactual $\tilde{y}_t^i = E\left[y_t^i | d_t^i = E\left[d_t^i\right]\right]$ will be captured by a broad set of controls X_{t-1} in $t-1$ and time- and country-fixed effects (γ_t, ν_i). Gross capital formation, current account, exports, government consumption and reserves are chosen to clean the output growth from external shocks and government responses, previous growth rate will also be added to the set of controls. Finally, the time-varying component of expected losses will be captured by the interaction p_t^i of the local density of population and the local propensity to be hit.

$$y_t^i = \beta_d d_t^i + \beta_p p_t^i + \beta_x X_{t-1} + \nu_i + \gamma_t + \varepsilon_t^i$$

Up to this point, the issue of a potential endogeneity bias introduced by relying on declarations for d_t^i has not been discussed. The hypothesis under which direct losses are not correlated to unobserved GDP growth could allegedly be questioned. Let us suppose that there exists an arbitrage for over-declaring losses. On the one hand, it seems possible to attract international assistance by over-reporting. On the other hand, it might send a bad signal on government capacities and decrease future aid inflows or foreign direct investment inflows. By the same token, missing entries for declarations of damages could be related to underlying economic conditions and countries having suffered long chaos could be censored in EM-DAT. Under the hypothesis that objective proxies e_t^i are not correlated to unpredicted growth of domestic production except through the measure of direct losses, the following two-stage model is identified.

$$\begin{cases} d_t^i = \alpha_e e_t^i + \alpha_p p_t^i + \alpha_x X_{t-1} + \rho_i + \delta_t + \mu_t^i & (1) \\ y_t^i = \beta_d \widehat{d_t^i} + \beta_p p_t^i + \beta_x X_{t-1} + \nu_i + \gamma_t + \varepsilon_t^i & (2) \end{cases} \tag{S}$$

In order to get rid of the classic Nickell's bias in those dynamic panel estimations with fixed effects, I will use the Arellano-Bond difference GMM estimator with one lag.

The identification method relies on a two step process. First, declared losses are predicted by objective measures. The second step is the estimation of the transmission of direct damages into indirect economic losses. As objective measures will be computed using past densities of population and the occurrences of typhoons and earthquakes, it is unlikely correlated with unpredicted growth conditional on the value of declared damages.

An important restriction of this specification is that it imposes a constant transmission parameter β_d across countries, leaving aside the possibility that economies might differ in their ability to recover from severe capital shocks.

Note that simpler reduced-form equations will also be estimated where the level of damages will be directly proxied by the objective measures of exposure.

$$y_t^i = \beta_d e_t^i + \beta_p p_t^i + \beta_x X_{t-1} + \nu_i + \gamma_t + \varepsilon_t^i \tag{Sr}$$

B. Data sources

As regards the macroeconomic indicators y_t^i and X_{t-1}^i, I use the World Development Indicators and Global Development Finance and keep an unbalanced panel of more than 180 countries between 1980 and 2006, which constitutes around 5000 country/year observations.

Declarations of direct damages $d_t^i = D_t^i/Y_t^i$ are extracted from a catalog of natural disasters. EM-DAT[4] represents the most complete public database on natural disasters, listing approximately 9300 catastrophes since 1968, of which 780 earthquakes, 2600 wind storms. Apart from the nature of the catastrophe, the location and exact time of its occurrence, EM-DAT gives indicators of magnitude if any, the associated disasters in the aftermath of the first shock, the criterion on which the EM-DAT team has selected this particular catastrophe[5] and more importantly, the number of people affected, homeless, injured or killed, economic damages, part of those damages covered by insurance, the aid contribution, the potential request for international assistance... Data entries are very often truncated to zero when it comes to economic or human damages. More than 3/4 of the entries do not provide any information on economic losses. In particular, as the thresholds for appearing in EM-DAT are often in absolute terms, small economies are relatively under-represented. In addition, the selection process might be influenced by endogenous factors particularly when the trigger is a declaration of emergency. A country where the government is completely inefficient might want to conceal this state failure to potential partners and thus might fear international assistance.

The objective measures of exposure to earthquakes and cyclones are constructed using two main indicators: a proxy for the natural threat, i.e. the energy dissipated by a catastrophe and a proxy for the assets at stake, i.e. the local density of population.

From Joint Typhoon Warning Center and PREVIEW Global Cyclones Asymmetric Wind speed Profile, I extract the wind structure of tropical typhoons, cyclones and hurricanes recorded by the regional centers from 1980 to 2006 (Unisys Weather, Bureau of Meteorology, Australia, Fiji Meteorology Service, Météo France, Japan Meteorological Agency, Joint Typhoon Warning Center provide tracks and wind intensity, pressure, location, form and size of the eye documented every 6 hours.). These data represent a quasi-exhaustive map of cyclones and typhoons; in total,

[4]EM-DAT: The OFDA/CRED International Disaster Database (www.emdat.be), Université Catholique de Louvain.

[5]this criterion relies on official declarations, and requires a minimum level of victims, or damages. A catastrophe which does not 'pass' these two tests can still appear in EM-DAT had the status of natural disaster been declared by authorities.

the datasets group 1866 events, only part of them having landed. For each event, the maximum local wind speed is calculated around the trajectory thanks to an augmented Holland formula accounting for both the rotation and translation of the cyclone and the position of the eye. Earthquakes are extracted from the catalogs produced by the USGS and National Geophysical Data Center. The database goes from 1965 to 2006 and data can be extracted for earlier events (even if the availability of macroeconomic data before 1970 limits the advantage of doing so). Information is given about the identity of the fault, the magnitude and type of measure, the date, the position of the epicenter and the depth. Overall, the datasets group 20000 tremors with a magnitude above 5.

Local population densities are extracted from the Gridded Population of the World[6]. Data have a 2.5 arc-minutes resolution and details the local density (per square kilometer) in 1990, 1995, 2000, 2005 using census surveys. The densities are adjusted so that the aggregate measure matches UN totals.

The map F2 in the appendix represents the sum of all wind-hazards between 1980 and 2006 coupled with a picture of density in 2005.

II. Measures of objective exposure to natural shocks

A. Data construction

This section documents the construction of local objective indicators for a particular area affected by a catastrophe and the aggregation of these local measures to an aggregated measure for each catastrophe.

Measures of natural threat

The first objective of the construction is to derive a local measure of natural threat. For reasons of consistency between earthquakes and wind-based events, I rely on the energy dissipated in a certain area. As it is not possible to derive the pressure exerted

[6]project created by the Center for International Earth Science Information Network (CIESIN), Columbia University and Centro Internacional de Agricultura Tropical (CIAT).

by a typhoon or an earthquake on buildings, infrastructures or crops, the energy dissipated is the best alternative to estimate potential economic direct damages.

For cyclones, Bister and Emanuel [1998] and Emanuel [2005] propose a measure of instantaneous exposure proportional to the cube of wind speed $E_c \propto v^3$. The derivation of this formula is detailed in the appendix and hinges on the hypothesis that energy dissipated is the same across the globe for a given wind intensity. As shown in the appendix, this is equivalent to assuming that regions are similarly rugged around the globe and that the air mass density is a constant. The only needed indicator is thus the local wind around the trajectory, which is already documented in the PREVIEW dataset.

For earthquakes, works initiated by Hanks and Kanamori [1979] to replace the Richter scale immediately relate measures of intensity (M_w moment magnitude) with the seismic moment. The total energy dissipated during an earthquake can be disentangled into three different sources: energy dissipated by generating new cracks in rock, energy dissipated as heat through friction, and energy elastically radiated through the earth. The seismic moment measures the latter. However, this measure is the energy dissipated at the focal point as M_w is given by geological institutes at the epicenter of the tremor. I construct here equivalent local moments[7] M_w for each point close to the epicenter, correcting for distance attenuation (see the appendix for the formula and underlying assumptions). The basic intuition is that there is an initial quasi-nil attenuation in a radius of 10-20 kms, then a steady attenuation with an acceleration after 100kms. As before, the estimations implicitly ignores regional differences, faults' shapes and soil types. Accordingly, the propagation of the earthquake will be supposed radially constant and the only needed variables will be the position of the epicenter, the focal depth and the seismic moment at the epicenter. Notwithstanding, there are no evident biases induced by these approximations.

[7]Peak Horizontal Acceleration to be more precise but PHA is very correlated with seismic moment and earthquake loss.

Measures of exposure

So far, we have the local energy dissipated for each event around its trajectory, but pure dissipation of energy alone is a poor indicator of direct damages. These estimates need at least to be weighted by the quantity of assets at stake and ideally account for the transmission of this energy to physical capital. The only local available information on capital at such a disaggregated level is the density of population. The simplest way to compute a measure of exposure is then to interact the energy with the quantity of assets at stake in a local area τ - approached by the population $d_e(\tau)$. Two types of measures might then be related to direct damages for a given event:

- the total energy dissipated weighted by the population $E(\tau)d_e(\tau)$ for a particular area τ and $\int E(\tau)d_e(\tau)d\tau$ along the whole catastrophe.
- the proportion of the population exposed to at least a certain threshold of energy E, $\mathbb{1}_{E(\tau)\geq E}d_e(\tau)$ for a particular area τ and $s_i = \int \mathbb{1}_{E(\tau)\geq E_i}d_e(\tau)d\tau$ along the whole catastrophe. Regarding cyclones, 6 thresholds $E_1, ..., E_6$ are defined along the categories given to tropical typhoons by NOAA (from tropical storm, which will be assigned to category 0 to category 5 typhoons). Similarly, for earthquakes, the thresholds of energy will be computed such as to match the Mercalli scale, from IV (mild tremor) to IX (heavy damage). Accordingly, 6 measures $s_0, ..., s_5$ are computed for each catastrophe representing the population affected by these 6 thresholds.

Here, economic vulnerability is only captured by the local density of population. First, it could be a weak indicator of capital density. Wealth and capital could be more concentrated than population. Capital density exhibits increasing returns to population density. I will ignore such correction as it does not provide significant improvement on the predictive power of the index developed here. Second, this construction also neglects the fact that different zones may differ in their resistance to a similar level of energy; light constructions are vulnerable to cyclones, not much to earthquakes. In addition, building requirements go a long way into explaining the vulnerability to earthquakes.

Losses due to natural disasters are only random in the sense that an occurrence can not be circumvented before it occurs. Economies can however react to ex-ante propensities of being hit and design proper institutions to mitigate the economic repercussions. Informal mechanisms and the presence of natural disaster funds in Philippines or Vietnam are often correlated with the regional exposure. Formal institutions in California, Florida, Japan, Netherlands ensure that a sufficient level of investment in mitigation issues is provided in the construction of new buildings. The differential impact on risky zones and riskless ones might bias the results and overweight the responses of highly exposed economies. Despite little evidence on systematic mitigation, it is reasonable to think that security norms might be tighter in disaster-prone areas. Under this assumption, I would underestimate the reach of natural disasters. On the opposite, people living in risky zones could be uninformed and have poor mitigation mechanisms once affected by a natural catastrophe. Along these lines, this bias would artificially distort the importance of natural disasters as disasters would mostly occur in places where unobserved mitigation is weak.

B. Descriptive statistics

Figure F3 in the appendix shows the geographic dispersion of affected countries for both cyclones and earthquakes. Earthquakes essentially occur along the faults existing between tectonic plates. As they result from deformations caused by major irregularities in the fault trace, the zone in which the probability of occurrence is non nil remains quite restricted. To sum up, the eastern part of the ring of fire, threaten the whole coast going from Alaska to Chile while the western counterpart provoke frequent tremors in Japan, China, Philippines, Indonesia. Finally, the eurasian fault affect mainly India, Pakistan, Iran, central Asia, Turkey, Greece. Cyclones, hurricanes or typhoons develop mainly in 5 basins: the extremely active West-Pacific basin where typhoons threaten the whole east-asian coast from Philippines and Vietnam to the borders of Russia, the East-Pacific basin (Hawaii and Mexico), the Indian basin (Madagascar, Mozambique, Mauritius for the southern Indian ocean, India, Bangladesh for the northern part), the Australian basin (Australia, small islands of the southern Pacific ocean) and the active Atlantic basin (Caribbean countries, Central America and United States). Overall, the dataset cover almost 120 countries for both type of events, and between 1 and a dozen of events per country per year. The intersection of the sets of countries affected by cyclones and earthquakes is far from being empty. Table T9 shows some statistics on affected countries. Note that cyclones and earthquakes tend to affect poor countries, differences between cyclones and earthquakes are not obvious despite island countries being more prone to wind exposure. Few countries concentrate a lot of the overall exposure. The medals' table rewards a heterogeneous panel of countries, going from the richest such as Japan or United States to Asian developing economies or least-developed countries. Based on economic and human losses reported in EM-DAT, table T10 presents some well-known catastrophes of our surveyed window (1980-2006). As expected, Katrina and Kobe's earthquakes were the costliest events during this period. Nonetheless, this also shed light on the particular case of island-countries and overcrowded Central America countries incurring small absolute losses but large relative losses once normalized to the size of their economies. Andrew, Katrina or Kobe's earthquake display small relative losses of the order of 1% of the annual production. The earthquake in Salvador or the hurricane Mitch in Honduras were larger shocks from this perspective.

C. Predicting declared losses

Matching catastrophes reported in EM-DAT with the constructed measures, I investigate how the latter relate with reported losses. The results tend to support the use of objective measure as instruments. On the one hand and this is fortunate, objective measures of exposure are good predictors of both reported damages and affected population. On the other hand, as already mentioned, there is a serious issue of censorship in declarations of damages, which justifies the use of an instrument to clear the estimation from unobserved components influencing the reports.

So as to establish the correlation between subjective and objective measures, wind-based events and earthquakes need to be matched to their counterparts in

EM-DAT. Surprisingly, this matching is quite difficult to implement[8]. As such, the country/year matching imposed by the macroeconomic data will prove surprisingly useful. Overall, only 75% of wind-based events in the EM-DAT dataset are given an objective exposure (around 1600 observations) and approximately 500 earthquakes. Conversely, a huge number of objective catastrophes having actually landed does not appear in EM-DAT. A small part of them is due to poor matching and the majority reflects the censorship in EM-DAT. In addition to censorship, entries are very often truncated to zero when it comes to economic or human damages. In the end, only 188 earthquakes and 260 wind-based events end up with a non-zero measure of damages over the period. Given the amplitude of truncation/censorship issues, I will display two types of correlation, (1) a correlation conditional on damages being documented, (ii) an unconditional correlation close to the hypothetical first stage relating declared losses to natural exposure. Tables T3 and T4 document the predicting power of the different measures of exposures, i.e. the energy weighted by the local population and populations affected by the different thresholds of energy.

On the one hand, the different thresholds do predict part of the variation in reported losses (around 30% of the variance can be explained by these objective measures). When 100% of the country population lives in in areas affected by the minimum threshold $s_0 = 1$ for a cyclone (resp. IV Mercalli scale for earthquakes), 1.9% (resp. 0.9%) of the population will be directly affected by the event and be injured or displaced. The same exposure incurs losses of the order of 2.8% of GDP (resp. 1.3%). Naturally, this is not the only exposure to this low level of energy which generates such losses, cyclones which hits a large part of the population mildly also hit a smaller fraction more strongly. The inclusion of indices computed for higher levels of exposure $s_1, ..., s_4$ globally supports the intuition. Higher levels of energy generates higher losses for a same proportion of population affected. When 100% of the population lives in areas affected by a category-2 typhoon $s_2 = 1$, $6-7\%$ of the total population are injured, killed or displaced and damages of the order of 10%

[8]One report on earthquakes needs to be attributed several tremors. EM-DAT does not provide conventional names for cyclones and some wind storms are too mild to be classified as such in the catalog of objective measures.

of GDP are recorded. Some coefficients are also negative and significantly so. One explanation is that the different measures are very correlated.

On the other hand, as highlighted by figure F1, the results are diluted by the inclusion of censored observations. The part explained by objective measures become much weaker, around 10% of the variance. Accordingly, using declared damages without instruments should lead to biased estimations for immediate production slack had this censorship been correlated with the recovery of the economy.

III. Amplitude of economic disruption

In this section, I document the amplitude of the economic slack following a shock.

First stage

Before analyzing the effect of direct losses on domestic production, let us analyze the first stage of the two stage strategy presented in the first section. For this specification, the estimation hinges on country/year aggregates and not catastrophe observations. Accordingly, both the reports and the objective measures are summed over country/year, weighting for the number of months for which the shock may have slowed down production. Denoting $x^i_{t,m}(c)$ the exposure index for a catastrophe occuring in year t, month m in country i, $x^i_t = \sum_c x^i_{t,m}(c)\frac{12-m}{12}$ will be the country/year counterpart.

Tables T5 and T6 highlight that objective estimates are very good predictors of declared damages, both in the case of earthquakes and wind-based hazards. Unsurprisingly, wind-based exposure does not have any influence on earthquake-related losses and the reciprocal statement can also be made. Note however that objective measures have a larger predictive power in the case of wind-based events. The truncation issue seems to be particularly acute in the case of earthquakes. Table 1 reinforces this conclusion as quake-based measures do not predict cumulated losses due to wind-based and geological hazards. 10% of the population affected by a category 0 cyclone generates losses of the order of .11 GDP points. This estimate

Table 1: Predicting declared losses - the link between declared damages and objective measures

Specification (S) - hypothetical first stage						
VARIABLE	**Annual damages declared in EM-DAT (% GDP)**					
Energy×density	.00248***					
(cyclones)	(.00017)					
s_0		.01171***	.00399***	.00552***	.00476***	.00435***
(cyclones)		(.00079)	(.00099)	(.00097)	(.00097)	(.00095)
s_1			.02540***	-.00417	.00307	.00336
(cyclones)			(.00202)	(.00275)	(.00283)	(.00279)
s_2				.06465***	.02403***	.02185***
(cyclones)				(.00419)	(.00592)	(.00585)
s_3					.05998***	.08820***
(cyclones)					(.00624)	(.00668)
s_4						-.14950***
(cyclones)						(.01364)
Energy×density	.00024					
(quakes)	(.00016)					
s_0		.00078*	.00052	.00022	.00040	.00041
(quakes)		(.00046)	(.00072)	(.00070)	(.00070)	(.00069)
s_1			.00155	.01031***	.01050***	.01084***
(quakes)			(.00271)	(.00379)	(.00379)	(.00374)
s_2				-.03297***	-.03086***	-.03248***
(quakes)				(.01077)	(.01104)	(.01091)
s_3					-.02248	-.04354
(quakes)					(.02690)	(.02920)
s_4						.10390*
(quakes)						(.05959)
Adj. R-squared	.05540	.05779	.08670	.12980	.14550	.16596
p-value(quakes)	.132	.091	.158	.003	.004	.001
p-value(cyclones)	.000	.000	.000	.000	.000	.000
Propensities	yes	yes	yes	yes	yes	yes
FE	country	country	country	country	country	country
Observations	5,171	5,171	5,171	5,171	5,171	5,171

Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. The results are shown omitting the coefficients for propensities to be affected and fixed effects. Robust standard errors are reported in parentheses.

increases to .25 and .65 points of GDP for categories 1 and 2 cyclones. These figures are increasing with the considered thresholds but not very smoothly: the coefficient before s_4 is negative, probably illustrating the strong correlation with s_3. In the rest of the paper, robustness checks will be performed so as to ensure the choices of instruments for the first stage do not shape the results of the second stage. When put together, only wind-based events remain - as put forward by the tests of joint nullity ($p = 0$ for cyclone measures and $p > .20$ for earthquake measures except when the inclusion of two very correlated variables, the exposure to thresholds VI and VII help predict damages due to cyclones!). Except when specified, from then on, the measures of damages will be the sum of quakes and cyclones damages incurred during the year.

Table 2: Influence of direct losses on domestic production

Specification (S) - second stage						
Panel A						
VARIABLE	**First difference of output growth $y_t - y_{t-1}$**					
Damages (% GDP) d_t	-0.055	-0.139	-0.388	-0.390***	-0.374***	-0.386***
	(0.041)	(0.322)	(0.252)	(0.136)	(0.134)	(0.104)
Instruments	-	$s_0^{c,q}$	$s_{0,1}^{c,q}$	$s_{0,1,2}^{c,q}$	$s_{0,1,2,3}^{c,q}$	$s_{0,1,2,3,4}^{c,q}$
Controls	-	-	-	-	-	-
Propensities	yes	yes	yes	yes	yes	yes
Observations	5,098	5,098	5,098	5,098	5,098	5,098
Panel B						
VARIABLE	**First difference of output growth $y_t - y_{t-1}$**					
Damages (% GDP) d_t	-0.059	-0.008	-0.444*	-0.455***	-0.444***	-0.447***
	(0.107)	(0.310)	(0.238)	(0.095)	(0.093)	(0.094)
Instruments	-	$s_0^{c,q}$	$s_{0,1}^{c,q}$	$s_{0,1,2}^{c,q}$	$s_{0,1,2,3}^{c,q}$	$s_{0,1,2,3,4}^{c,q}$
Controls	yes	yes	yes	yes	yes	yes
Propensities	yes	yes	yes	yes	yes	yes
Observations	3,986	3,986	3,986	3,986	3,986	3,986
Panel C						
VARIABLE	**Output growth y_t**					
Damages (% GDP) d_t	-0.137**	0.054	-0.133	-0.200*	-0.190*	-0.222**
	(0.053)	(0.139)	(0.124)	(0.107)	(0.101)	(0.099)
Instruments	-	$s_0^{c,q}$	$s_{0,1}^{c,q}$	$s_{0,1,2}^{c,q}$	$s_{0,1,2,3}^{c,q}$	$s_{0,1,2,3,4}^{c,q}$
Controls	yes	yes	yes	yes	yes	yes
Propensities	yes	yes	yes	yes	yes	yes
Observations	3,986	3,986	3,986	3,986	3,986	3,986

Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. Declared losses are annual losses from earthquakes or wind-based events divided by current GDP. The results are shown omitting the coefficients for propensities to be affected, fixed effects and controls: gross capital formation, government consumption, total reserves, current account, domestic credit, imports, FDI inflows and GDP per capita. Standard errors are clustered at country level. The specifications are simple 2SLS in panels A and B and Arellano-Bond difference GMM estimator with one lag in panel C.

Second stage

Let us turn to the second stage. Table 2 documents the link between reports and output growth. The OLS estimation concerning the effect of direct losses on domestic production shows that economies face a slowdown in the aftermath of calamities. As shown in table 2, reported losses of 1 point of GDP yield a slack accounting for approximately .05 of GDP growth. The results are robust to the addition of country- or time- fixed effects and other controls. Nonetheless, this robustness does not give support to the exogeneity of declared damages. Instrumenting by physical exposure, the consequences of direct losses increase to a large extent, a feature that tends to point out the existence of a fixed and systematic bias relating unobserved determinants of growth and declared losses. The indirect losses climb up to roughly 40% of the initial capital losses. Incidentally, these results are statistically significant and robust to the addition of fixed effects with Arellano-Bond System GMM estimator with 1-period lags, other controls and even to the choice of instruments (corrected sum of exposure, thresholds...). Note that the results are stable through the different specifications.

Let us detail the composition of the set of controls composing X_{t-1}. The construction of these sets relies on the objective to capture the main determinants of conjuncture and isolate as much as possible the unexpected growth component. The advantage of the instruments used here is that there is no need to control for omission bias as physical exposure is independent from any unobserved and underlying determinants of growth. Consequently, gross capital formation accounts for shocks on returns to capital and confidence crisis, while total reserves to GDP stands for immediate financing capacities[9]. Current account and government consumption reflect also potential budget shock. Additionally to this basic set, domestic credit captures the degree of credit constraints, and exports, imports, foreign debt and foreign direct investment inflows account for external shocks.

[9]Unsurprisingly, these controls are pro-cyclical.

Table 3: Influence of natural exposure on domestic production

Cyclones

PANEL A

Regressand	$y_t - y_{t-1}$	$y_t - y_{t-1}$	y_t	y_t
Regressors				
s_0	-0.002	-0.001	-0.002	0.002
(cyclones)	(0.002)	(0.002)	(0.003)	(0.003)
	5,098	*3,986*	*5,098*	*3,986*
s_1	-0.014***	-0.013***	-0.012	-0.009
(cyclones)	(0.004)	(0.004)	(0.007)	(0.006)
	5,098	*3,986*	*5,098*	*3,986*
s_2	-0.031***	-0.038***	-0.025*	-0.030**
(cyclones)	(0.010)	(0.011)	(0.013)	(0.012)
	5,098	*3,986*	*5,098*	*3,986*
s_3	-0.040**	-0.060***	-0.030	-0.045**
(cyclones)	(0.018)	(0.022)	(0.019)	(0.018)
	5,098	*3,986*	*5,098*	*3,986*
s_4	-0.009	-0.128**	0.008	0.089
(cyclones)	(0.043)	(0.060)	(0.058)	(0.202)
	5,098	*3,986*	*5,098*	*3,986*
Specifications	OLS	OLS	AB	AB
Controls	-	yes	-	yes
Propensities	yes	yes	yes	yes

Earthquakes

PANEL B

Regressand	$y_t - y_{t-1}$	$y_t - y_{t-1}$	y_t	y_t
Regressors				
s_0	0.001	0.001	0.001	-0.001
(quakes)	(0.002)	(0.002)	(0.002)	(0.002)
	5,098	*3,986*	*5,098*	*3,986*
s_1	-0.002	-0.003	-0.003	-0.009
(quakes)	(0.004)	(0.005)	(0.007)	(0.006)
	5,098	*3,986*	*5,098*	*3,986*
s_2	0.002	-0.003	-0.004	-0.021
(quakes)	(0.015)	(0.018)	(0.028)	(0.024)
	5,098	*3,986*	*5,098*	*3,986*
s_3	-0.033	-0.038	-0.012	-0.036
(quakes)	(0.030)	(0.034)	(0.100)	(0.081)
	5,098	*3,986*	*5,098*	*3,986*
s_4	-0.075	-0.104*	-0.035	-0.220
(quakes)	(0.070)	(0.055)	(0.255)	(0.207)
	5,098	*3,986*	*5,098*	*3,986*
Specifications	OLS	OLS	AB	AB
Controls	-	yes	-	yes
Propensities	yes	yes	yes	yes

Each element of the table is the result of a separate regression. Four main specifications are considered, an OLS estimator and an Arellano-Bond difference GMM estimator with one lag, both computed without and with controls. Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. Robust standard errors are reported between brackets and the number of observations is in italics. The results are shown omitting the coefficients for propensities to be affected, fixed effects and controls: gross capital formation, government consumption, total reserves, current account, domestic credit, imports, FDI inflows and GDP per capita.

Reduced-form specification

Not only physical exposure is a good instrument, but also simply a good predictor of indirect losses independently of declarations. As reports on earthquakes are quite rare, the previous specification is not very informative when restricting to these events. The only way to cleanly disentangle the role of quakes and wind-based events would be to bypass declared damages and estimate the economic slack in a reduced-form specification.

As made explicit in table 3, the physical annual exposure predicts an economic slack in the case of cyclones (panel A). A production slack of .14 (resp. .4 and .6) points of GDP echoes an additional 10% of the population affected at least by a category 1 (resp. 2 and 3) event. Even though the framework here is not completely fit for applying the Wald estimator, the coefficient found during the regressions above are consistent with the Wald approach. Comparatively, panel B displays a negative but consistently insignificant influence of earthquakes on output.

IV. Discussion

Interpretation

In this part, I will try to be conservative and give the lowest bound for the residual of output loss unexplained by capital losses. Before computing estimates, let me come back to the Cobb-Douglas benchmark and compute estimates of a production slowdown following capital losses. Consider in this regard that direct damages reported in EM-DAT are losses of productive capital. In practice, those losses also encompass the destruction of unproductive units of capital. The production sector of the economy has a standard production technology $Y = AK^{\alpha}L^{1-\alpha}$ using capital K and labor L as inputs with returns r and w. After a log-differentiation,

$$y = \frac{dY}{Y} = \frac{dA}{A} + \alpha\frac{dK}{K} + (1-\alpha)\frac{dL}{L}$$

Note that, under the assumption that direct reports d_d are exactly capital losses normalized by GDP, $dK/K = d_d Y/K$. The previous equation then becomes

$$y = \alpha \frac{Y}{K} d_d + (1-\alpha)\frac{dL}{L} + \frac{dA}{A}$$

In a first instance, assume that the labor supply and the technological productivity are both unchanged.

$$\frac{y}{d_d} = \alpha(Y/K)$$

A very conservative value for the ratio GDP/productive capital would be 1/8 while α is around 1/3. Consequently, the elasticity of output loss should be lower than .05 (which represents also an upper bound for the marginal productivity of capital as $\alpha(Y/K) = r$) under the previous assumptions. The predicted value of y/d_d is far lower than the coefficient .4 found in the empirical specifications.

Keeping the assumption that $dA/A = 0$, let us relax the assumption that labor markets do not adjust. The optimization specifies that $A(1-\alpha)K^{\alpha}L^{-\alpha} = w$. If wages are rigid, the labor demand from firms adjusts since wages are temporarily too high. A decrease of capital is then followed by the same decrease in labor $dK/K = dL/L$. The ratio capital/labor is kept constant, the interest rate remains the same and households keep the same consumption/savings behavior. To put it simply, the economy shifts to a lower equilibrium (see the recent discussion on jobless recoveries and Shimer [2010] in particular). In this case,

$$\frac{y}{d_d} = Y/K$$

The elasticity of output loss is bounded by .12, still lower than .4. Consequently, in this stylized framework, the productivity shock dA/A should account at least for two third of the estimated losses. Note that in this framework, dA/A is a residual - Solow style - including everything that can not be explained by the simple Cobb-Douglas representation. For example, a temporary business disruption can be modeled as an economy with strong complementarities between sectors.

At the end of 2010, Paris was hit by a very mild snowstorm (from a thin layer to 20 centimeters of snow for some places). This event prevented workers from going to work because roads needed to be cleaned and electricity to be restored. Pure capital losses were almost nil but the economic activity slowed down seriously during few days. Thinking about roads and electricity as two different kinds of capital, this example illustrates that capital can be thought of as the product of strong complementarities between many kinds of capital. When an event affects strongly one of the capital inputs (roads, electricity...), the response of the economy may put into question the aggregate approximation $K^\alpha L^{1-\alpha}$ for the production of the final good. With $K = \left(\int_0^1 K_i^\rho di\right)^{1/\rho}$, ρ would capture the complementarities between the different kinds of intermediary capital. With this assumption, the effect of having a fraction δ of capital destroyed on production goes from $\alpha\delta$, the mildest situation where the capital is similarly affected to $\alpha\left((1-\delta)^{1/\rho} - 1\right)$, the sharpest slack in production due to very localized losses. The slack may then highlight this complementarity between sectors which does not appear in normal recession (as the initial shock may be much more spread than in the case of natural disasters).

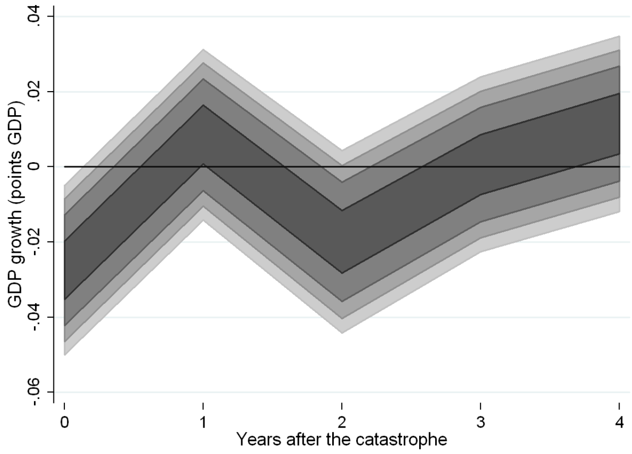
This feature may also indicate that most of the immediate losses are due to business disruption affecting productivity, labor supply... This interpretation is backed up by anecdotal evidence. The chaos in the aftermath of large events often outshines the capital stock decrease. The next section indirectly confirms the impression that most of the immediate slack is due to a temporary freeze of the economy.

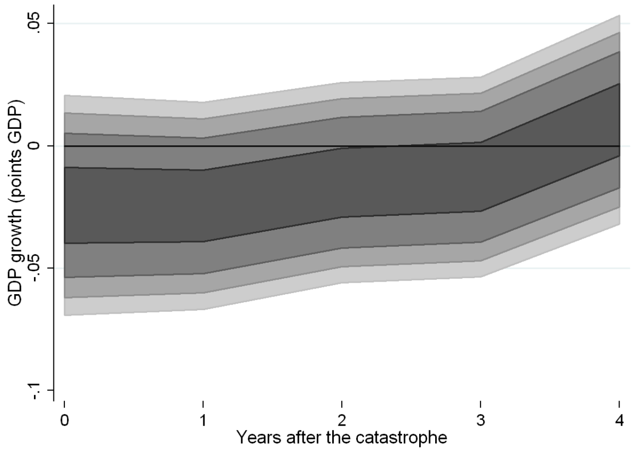
Catching-up with the growth path?

The previous section has highlighted the presence of an economic slack created by natural disasters. Building on the previous analysis, quick recovery should be expected if the major impact is to be related with a productivity freeze. However, some economic fundamentals might be severely affected and the economy could suffer from a long period of unrest. Saint-Kitts and Nevis exhibited a long slowdown some years after the passing of Georges in 1998, which might be due to non-restored capital stocks. In this section, I try to describe how well economies represented in the sample catch up with their growth path.

As reported in table 4 and figure 1 considering the estimates of the most de-

Figure 1: evolution of GDP growth, left panel: cyclones, right panel: earthquakes. Areas in gray represent 50%, 20%, 10% and 5% confidence intervals.





manding specifications ((4) and (8)), the immediate effect of cyclones on economic production is temporary. An additional 10% of the population affected at least by a category 2 event induces an immediate economic slack of .34 points of GDP growth, offset one year later. Still, there are no evidence of a mean reversion. As such, the growth one year after the shock is around the pre-shock excess growth. In other words, the economies are not back to the tracks that cyclones forced them to leave, they only retrieve in $t + 1$ their growth level of $t - 1$. Catching-up here does not mean coming close to the counterfactual path (had the country not been affected by the catastrophe) but growing parallel to that path.

Table 4: Influence of natural exposure on domestic production - including lags

Panel A	**Cyclones**			
VARIABLE	**First difference** $y_t - y_{t-1}$		**Output growth** y_t	
s_2	-.034***	-.041***	-.023*	-.027**
(cyclones)	(.009)	(.011)	(.012)	(.012)
L.s_2	.016	.024*	.011	.009
(cyclones)	(.012)	(.014)	(.012)	(.012)
L2.s_2	-.029**	-.035**	-.019	-.020
(cyclones)	(.012)	(.015)	(.012)	(.012)
L3.s_2	.017	.024	.000	.001
(cyclones)	(.016)	(.019)	(.012)	(.012)
L4.s_2	.021	.012	.016	.011
(cyclones)	(.018)	(.015)	(.014)	(.012)
Controls	-	yes	-	yes
Propensities	yes	yes	yes	yes
FE	-	-	country	country
Observations	4,646	3,651	4,646	3,651

Panel B	**Earthquakes**			
VARIABLE	**First difference** $y_t - y_{t-1}$		**Output growth** y_t	
s_2	0.005	-0.005	-0.012	-0.024
(quakes)	(0.017)	(0.018)	(0.027)	(0.023)
L.s_2	-0.010	-0.009	-0.029	-0.025
(quakes)	(0.017)	(0.017)	(0.026)	(0.022)
L2.s_2	0.022	0.014	-0.001	-0.015
(quakes)	(0.017)	(0.018)	(0.026)	(0.021)
L3.s_2	0.002	-0.003	-0.005	-0.013
(quakes)	(0.012)	(0.011)	(0.026)	(0.021)
L4.s_2	0.016	0.015	0.018	0.011
(quakes)	(0.016)	(0.017)	(0.028)	(0.022)
Controls	-	yes	-	yes
Propensities	yes	yes	yes	yes
FE	-	-	country	country
Observations	4,646	3,651	4,646	3,651

Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. The results are shown omitting the coefficients for propensities to be affected, fixed effects and controls: gross capital formation, government consumption, total reserves, current account, domestic credit, imports, FDI inflows and GDP per capita. Standard errors are clustered at country level. The specifications are simple OLS for the first 2 columns and Arellano-Bond difference GMM estimator with one lag for the last 2 columns.

V. Concluding remarks

This paper has documented how large natural disasters might provoke a slowdown of production. The amplitude of the recession is particularly large in the case of wind-based events. Accordingly, most of this economic slack seems to be attributed to business disruption rather than capital losses. The recent exposure to the occurrences of dreadful cyclones do not seem to slacken the economy for more than one or two years on average. This observation confirms the intuition that the economic slowdown corresponds essentially to temporary productivity shocks.

While this article depicts the average response of economies, the results encourage us to explore avenues to understand through which mechanisms the first shock radiates and might be offset few months later. Do institutions matter in the way an economy recovers from a catastrophe? In particular, reallocation of resources (labor, technology, capital) should play a central role. Does the sectoral allocation of damages matter for the economic recovery? The differential response between earthquakes and cyclones indicates that these shocks either differ in nature or affect different economies.

Finally, a side result of this study concerns biases and censorship issues for reports from officials. They seem to be astonishingly large. The absence of reports in the aftermath of a catastrophe in some developing countries can be explained by the absence of NGOs and insurance. Still, no definite conclusions can be drawn on the reason why declared losses do not explain indirect losses. Further research could help determine if this result emerges from a voluntary declaration bias induced by signaling concerns, censored datasets or from the methodology used in those reports (NGOs focusing mainly on "non-economic losses").

References

Albala-Bertrand, J. M. 1993. "Natural disaster situations and growth: A macroeconomic model for sudden disaster impacts." *World Development*, 21(9): 1417–1434.

Bister, M., and K. A. Emanuel. 1998. "Dissipative heating and hurricane intensity." *Meteorology and Atmospheric Physics*, 65(3): 233–240.

Choy, George L., and John L. Boatwright. 1995. "Global patterns of radiated seismic energy and apparent stress." *Journal of Geophysical Research*, 100: 18205–18228.

Emanuel, Kerry. 2005. "Increasing destructiveness of tropical cyclones over the past 30 years." *Nature*, 436: 686–688.

Gassebner, Martin, Alexander Keck, and Robert Teh. 2006. "The Impact of Disasters on International Trade." *Working paper.*

Graizer, Vladimir, and Erol Kalkan. 2007. "Ground Motion Attenuation Model for Peak Horizontal Acceleration from Shallow Crustal Earthquakes." *Earthquake Spectra*, 23(3): 585–613.

Hanks, Thomac C., and Hiroo Kanamori. 1979. "A moment magnitude scale." *Journal of Geophysical Research*, 84: 2348–2350.

Hasegawa, H. S., P. W. Basham, and M. J. Berry. 1981. "Attenuation relations for strong seismic ground motion in Canada." *Bulletin of the Seismological Society of America*, 71(6): 1943–1962.

Herold, Christian, Frederic Mouton, Ola Nordbeck, and Pascal Peduzzi. 2006. "Preview Global Cyclones Asymmetric Windspeed Profile."

Kahn, Matthew E. 2005. "The Death Toll from Natural Disasters: The Role of Income, Geography, and Institutions." *The Review of Economics and Statistics*, 87(2): 271–284.

Kochar, Anjini. 1999. "Smoothing Consumption by Smoothing Income: Hours-of-Work Responses to Idiosyncratic Agricultural Shocks in Rural India." *Review of Economics and Statistics*, 81(1): 50–61.

Noy, Ilan. 2009. "The macroeconomic consequences of disasters." *Journal of Development Economics*, 88(2): 221–231.

Raddatz, Claudio. 2009. "The wrath of God : macroeconomic costs of natural disasters." The World Bank Policy Research Working Paper Series 5039.

Ramcharan, Rodney. 2007. "Does the exchange rate regime matter for real shocks? Evidence from windstorms and earthquakes." *Journal of International Economics*, 73(1): 31–47.

Rasmussen, Tobias. 2004. "Macroeconomic Implications of Natural Disasters in the Caribbean." *Working Paper.*

Rosenzweig, Mark R., and Kenneth I. Wolpin. 2000. "Natural "Natural Experiments" in Economics." *Journal of Economic Literature*, 38(4): 827–874.

Shimer, R. 2010. "Wage Rigidities and Jobless Recoveries." *Working Paper.*

Si, Hongjun. 1999. "New attenuation relationships for peak ground acceleration and velocity considering effect of fault type and site condition." *J. Struct. Constr. Eng.*, 523: 63–70.

Skidmore, Mark, and Hideki Toya. 2002. "Do Natural Disasters Promote Long-Run Growth?" *Economic Inquiry*, 40(4): 664–687.

Strömberg, David. 2007. "Natural Disasters, Economic Development, and Humanitarian Aid." *The Journal of Economic Perspectives*, 21: 199–222.

Strobl, Eric. 2011*a*. "The Economic Growth Impact of Hurricanes: Evidence from U.S. Coastal Counties." *Review of Economics and Statistics*, 93(2): 575–589.

Strobl, Eric. 2011*b*. "The economic growth impact of natural disasters in developing countries: Evidence from hurricane strikes in the Central American and Caribbean regions." *Journal of Development Economics*, –.

Toya, Hideki, and Mark Skidmore. 2007. "Economic development and the impacts of natural disasters." *Economics Letters*, 94(1): 20–25.

Wu, Yih-Min, Ta-liang Teng, Tzay-Chyn Shin, and Nai-Chi Hsiao. 2003. "Relationship between Peak Ground Acceleration, Peak Ground Velocity, and Intensity in Taiwan." *Bulletin of the Seismological Society of America*, 93(1): 386–396.

Yang, Dean, and HwaJung Choi. 2007. "Are Remittances Insurance? Evidence from Rainfall Shocks in the Philippines." *World Bank Econ Rev*, lhm003.

A Data sources

- National Earthquake Information Center (NEIC), a part of the Department of the Interior, U.S. Geological Survey: Earthquake catalog

- The Global Seismic Hazard Assessment Program (GSHAP) was launched in 1992 by the International Lithosphere Program (ILP) with the support of the International Council of Scientific Unions (ICSU), and endorsed as a demonstration program in the framework of the United Nations International Decade for Natural Disaster Reduction (UN/IDNDR).

- Gridded Population of the World: Socioeconomic Data and Applications Centre (SEDAC), of the of the U.S. National Aeronautics and Space Administration (NASA). and distributed by The Center for International Earth Science Information Network (CIESIN) at Columbia University.

- PREVIEW Global Cyclones Polylines Tracks created by UNEP/DEWA/ GRID-Europe (GNV199) from 1980 to 2006 (C.Herold, F.Mouton, O.Norbeck, P.Peduzzi)

- EM-DAT: The OFDA/CRED International Disaster Database (www.emdat.be), Université Catholique de Louvain.

B Construction of the energy dissipated

A. Cyclones

The local maximum wind speed around the trajectory is extracted from the PREVIEW Global Cyclones Polylines Tracks. Herold et al. [2006] describes in details how the dataset is constructed from the tracks of cyclones coupled with an augmented Holland formula.

The power dissipation P of a cyclone is the rate of energy dissipation per unit time per unit horizontal surface area. It depends locally on the excess wind speed v, the air mass density ρ and the surface drag coefficient C_d, accounting for the surface irregularities (vertical surface area per unit of horizontal surface area). The way to model it is the following.

The collision of a molecule with kinetic energy $\frac{1}{2}mv^2$ with an inelastic surface of surface area equal to 1 generates an energy loss of $\frac{1}{2}mv^2$ (supposing that the collision completely stops the molecule motion).

The vertical surface associated with a horizontal surface dS is $C_d dS$ by definition of the drag coefficient.

Now, let us consider the number of molecules entering into collision with a surface during a small amount of time $d\tau$. Taking the molecule cloud as a uniform group, the number of molecules which will hit a wall during $d\tau$ is the number of molecules at a distance lower or equal to $vd\tau$. If we consider a unit surface area, this number is simply $vd\tau\rho$.

As a consequence, the energy dissipated during time $d\tau$ for a given horizontal surface area dS is the product of those three quantities:

$$\frac{1}{2}\rho C_d v^3 d\tau dS$$

Below, I report the constants used for the computations of the indices of exposure, including the thresholds defining typhoon categories.

B. Earthquakes

Radiated energy

The construction of an index of energy for earthquakes is more complicated. In practice, only a part of the energy dissipated is captured by the seismic moment or by the peak horizontal acceleration. Here, I will ignore the other channels through which tremors dissipate energy and focus on peak ground acceleration as the predictor of damages. As put forward by Wu et al. [2003], the peak horizontal acceleration is

Table T1: Choice of parameters' values for the energy measures

Description	Parameter	Value	Units
	Cyclones		
Surface drag coefficient	C_d	0.47	-
Air mass density	ρ	1.2	kg/m^3
Threshold cat-0 typhoon	v_0	17.5	m/s
Threshold cat-1 typhoon	v_1	32.5	m/s
Threshold cat-2 typhoon	v_2	42.5	m/s
Threshold cat-3 typhoon	v_3	49	m/s
Threshold cat-4 typhoon	v_4	58	m/s
Threshold cat-5 typhoon	v_5	69	m/s

- stands for dimensionless quantities.

very correlated with earthquake losses[10]. In addition, this measure is generally used to set building regulations. The problem is that either the moment or the PHA are given at the focal point.

Dissipation

Denote d the distance to the epicenter[11], Y the peak horizontal acceleration, M the moment magnitude at the epicenter.

Many studies are devoted to the estimation of attenuation relationships for peak horizontal acceleration and velocity around the fault after an earthquake. These relationships strongly depend on regional characteristics (soil type, fault structure) but also on the type of earthquake (strike, slip or reverse). As I do not possess information on these characteristics for each tremor, I can only provide rough estimates accounting for the main features of this propagation, an initial quasi-nil attenuation, a global pattern in $1/d$ with an acceleration of the attenuation. I will use the estimates supplied by Graizer and Kalkan [2007] for shallow crustal earthquakes for

[10]Note that the use of peak ground velocity can be recommended in the case of very large earthquakes. As a robustness check, I construct the measure of exposure with this measure as well. The results provided in the paper are left unchanged.

[11]It is possible to construct the orthodormic distance d between two points of the earth surface just using latitude and longitude. Let us consider two points P and E and their respective longitude/latitude coordinates (ϕ_p, θ_p) and (ϕ_e, θ_e). A simple computation brings immediately:

$$d = r \arccos\left[\cos(\phi_p)\cos(\phi_e)\cos(\theta_p - \theta_e) + \sin(\phi_p)\sin(\phi_e)\right]$$

peak horizontal acceleration (and estimates in Si [1999] as a robustness check for peak horizontal acceleration and velocity).

The attenuation relationship can be written as the sum of 4 effects:

$$ln(Y) = \underbrace{F_1}_{\text{magnitude scaling}} + \underbrace{F_2}_{\text{core attenuation}} + \underbrace{F_3}_{\text{basin effect}} + \underbrace{F_4}_{\text{site conditions}}$$

where

$$\begin{cases} F_1 = ln\left[(c_1 arctan(M + c_2) + c_3)\, F\right] \\ F_2 = -0.5ln\left[(1 - r/(c_4 M + c_5))^2 + 4(c_6 cos(c7(M + c_8)) + c_9)^2 r/(c_4 M + c_5)\right] \\ F_3 = -0.5ln\left[\left(1 - \sqrt{r/r_1}\right)^2 + 4d_1^2\sqrt{r/r_1}\right] \\ F_4 = S \end{cases}$$

Below, the coefficients used in this study are reported, including the thresholds associating PHA values to Mercalli counterparts. Note that some assumptions are made in addition to those used by Graizer and Kalkan [2007]: (i) this relationship is valid for focal depth less than 20 kms, (ii) the coefficient F is fixed at 1 as if every earthquake were strike slip or normal (F is estimated at 1.28 for reverse earthquakes), (iii) site corrections are ignored ($S = 0$).

Table T2: Choice of parameters' values for the PHA relationship

Description	Parameter	Value	Units
	Earthquakes		
d	r	6371	km
F_1	c_1	0.14	-
	c_2	-6.25	-
	c_3	0.37	-
	F	1	-
F_2	c_4	2.237	-
	c_5	-7.542	-
	c_6	-0.125	-
	c_7	1.19	-
	c_8	-6.15	-
	c_9	0.525	-
F_3	r_1	100	km
	d_1	0.35	-
F_4	S	0	-
Threshold IV quake	Y_0	0.01	g
Threshold V quake	Y_1	0.04	g
Threshold VI quake	Y_2	0.09	g
Threshold VII quake	Y_3	0.18	g
Threshold VIII quake	Y_4	0.34	g
Threshold IX quake	Y_5	0.65	g

- stands for dimensionless quantities. Accelerations are expressed in $g = 9.81m/s^2$ The earth radius is considered constant here.

C Tables and figures

Table T3: Predicting declared losses - wind measures

Cyclones

Panel A										
VARIABLE	**Population declared as affected in EM-DAT (% population)**									
s_0	.0187***	.0054	.0068*	.0067*	.0068*	.0068***	.0025***	.0027***	.0027***	.0027***
	(.0030)	(.0037)	(.0036)	(.0035)	(.0035)	(.0007)	(.0009)	(.0009)	(.0008)	(.0008)
s_1		.0300***	.0116*	.0150**	.0150**		.0127***	.0064***	.0073***	.0073***
		(.0053)	(.0068)	(.0065)	(.0065)		(.0015)	(.0019)	(.0019)	(.0019)
s_2			.0387***	.0012	.0019			.0147***	-.0010	-.0007
			(.0092)	(.0112)	(.0112)			(.0027)	(.0034)	(.0034)
s_3				.0705***	.0563***				.0326***	.0284***
				(.0130)	(.0175)				(.0044)	(.0055)
s_4					.0352					.0099
					(.0291)					(.0077)
Sample	Catastrophes uncensored in EM-DAT					All catastrophes				
R-squared	.1097	.1912	.2344	.3004	.3036	.0511	.0919	.1074	.1358	.1366
Observations	317	317	317	317	317	1,657	1,657	1,657	1,657	1,657

Panel B										
VARIABLE	**Damages declared in EM-DAT (% GDP)**									
s_0	.0276***	.0158***	.0193***	.0196***	.0195***	.0064***	.0037***	.0040***	.0040***	.0040***
	(.0036)	(.0045)	(.0043)	(.0042)	(.0043)	(.0007)	(.0009)	(.0008)	(.0008)	(.0008)
s_1		.0299***	-.0070	-.0109	-.0110		.0080***	-.0006	-.0010	-.0010
		(.0072)	(.0098)	(.0096)	(.0097)		(.0015)	(.0019)	(.0019)	(.0019)
s_2			.0649***	.0952***	.0951***			.0205***	.0268***	.0267***
			(.0123)	(.0149)	(.0149)			(.0028)	(.0034)	(.0035)
s_3				-.0571***	-.0533**				-.0145***	-.0139**
				(.0165)	(.0227)				(.0047)	(.0063)
s_4					-.0086					-.0013
					(.0349)					(.0083)
Sample	Catastrophes uncensored in EM-DAT					All catastrophes				
R-squared	.1848	.2364	.3111	.3421	.3423	.0465	.0630	.0931	.0983	.0983
Observations	260	260	260	260	260	1,655	1,655	1,655	1,655	1,655

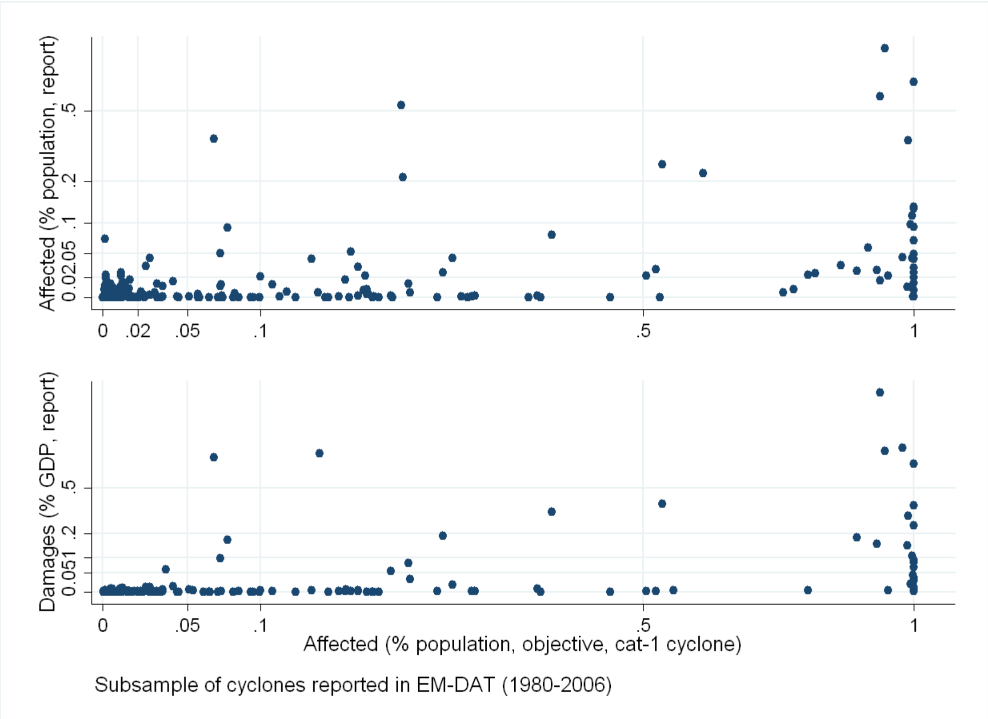
Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. Robust standard errors are reported in parentheses.

Table T4: Predicting declared losses - earthquake measures

	Earthquakes									
Panel A										
VARIABLE	**Population declared as affected in EM-DAT (% population)**									
s_0	.0091***	.0173***	.0183***	.0163***	.0072***	.0028***	.0024***	.0024***	.0023***	.0022***
	(.0008)	(.0018)	(.0019)	(.0019)	(.0022)	(.0001)	(.0002)	(.0002)	(.0002)	(.0002)
s_1		-.0268***	-.0420***	-.0400***	-.0149		.0017***	.0003	-.0005	-.0006
		(.0052)	(.0104)	(.0102)	(.0103)		(.0006)	(.0007)	(.0007)	(.0007)
s_2			.0437*	.0237	.0082			.0058***	-.0002	.0000
			(.0258)	(.0258)	(.0245)			(.0019)	(.0019)	(.0019)
s_3				.1683***	-.1503**				.0631***	.0523***
				(.0404)	(.0584)				(.0062)	(.0069)
s_4					2.0541***					.0535***
					(.2851)					(.0149)
Sample		Catastrophes uncensored in EM-DAT						All catastrophes		
R-squared	.2324	.2765	.2813	.3091	.3835	.0716	.0731	.0748	.0928	.0951
Observations	436	436	436	436	436	5,173	5,173	5,173	5,173	5,173
Panel B										
VARIABLE	**Damages declared in EM-DAT (% GDP)**									
s_0	.0130***	.0176***	.0170***	.0179***	.0145**	.0039***	.0035***	.0035***	.0035***	.0035***
	(.0017)	(.0041)	(.0048)	(.0048)	(.0057)	(.0002)	(.0003)	(.0003)	(.0003)	(.0003)
s_1		-.0184	-.0111	-.0238	-.0051		.0019**	.0015	.0011	.0011
		(.0149)	(.0341)	(.0345)	(.0384)		(.0009)	(.0011)	(.0011)	(.0011)
s_2			-.0207	.1016	.0706			.0013	-.0019	-.0018
			(.0877)	(.1094)	(.1128)			(.0028)	(.0029)	(.0029)
s_3				-.2860*	-.4219**				.0335***	.0304***
				(.1546)	(.1967)				(.0094)	(.0104)
s_4					.7943					.0150
					(.7119)					(.0224)
Sample		Catastrophes uncensored in EM-DAT						All catastrophes		
R-squared	.2318	.2380	.2383	.2523	.2573	.0720	.0728	.0729	.0751	.0752
Observations	188	188	188	188	188	5,174	5,174	5,174	5,174	5,174

Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. Robust standard errors are reported in parentheses.

Figure F1: subjective vs. objective measures, left panel: cyclones, right panel: earthquakes.



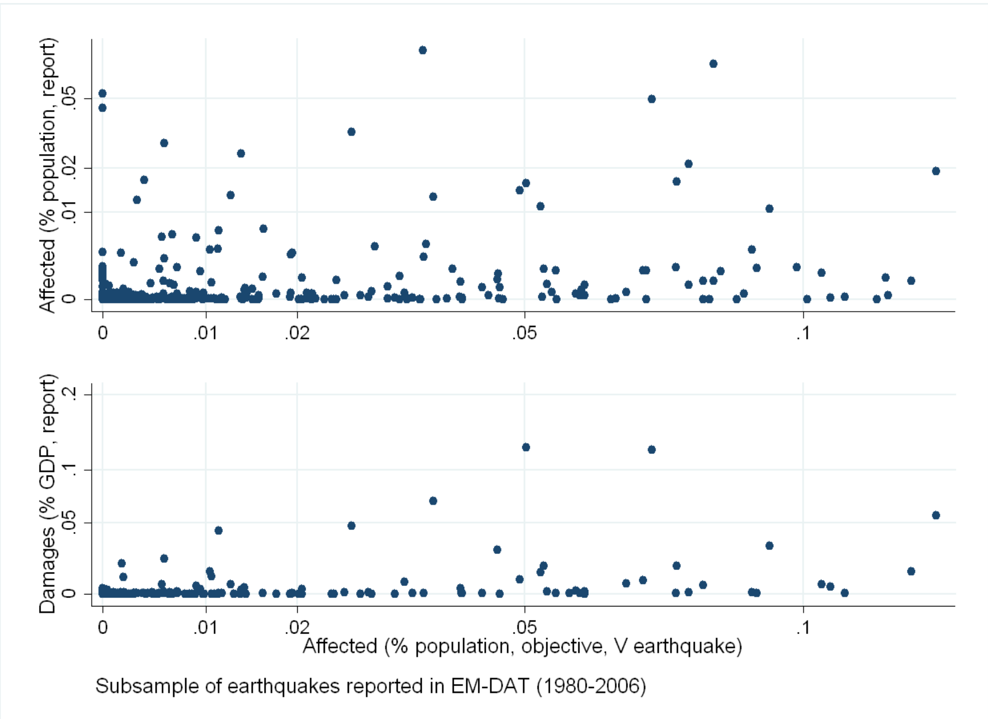


Table T5: Predicting declared losses - cyclones only

Specification (S) - hypothetical first stage

VARIABLE	**Annual damages declared in EM-DAT (% GDP)**					
Energy×density	.00248***					
(cyclones)	(.00017)					
s_0		.01173***	.00401***	.00554***	.00478***	.00437***
(cyclones)		(.00077)	(.00096)	(.00094)	(.00094)	(.00093)
s_1			.02542***	-.00410	.00311	.00338
(cyclones)			(.00196)	(.00267)	(.00275)	(.00271)
s_2				.06456***	.02409***	.02197***
(cyclones)				(.00407)	(.00575)	(.00568)
s_3					.05973***	.08790***
(cyclones)					(.00606)	(.00648)
s_4						-.14935***
(cyclones)						(.01324)
Energy×density	-.00017					
(quakes)	(.00016)					
s_0		-.00042	-.00052	-.00082	-.00063	-.00063
(quakes)		(.00045)	(.00070)	(.00068)	(.00068)	(.00067)
s_1			.00072	.00987***	.01016***	.01056***
(quakes)			(.00264)	(.00368)	(.00368)	(.00363)
s_2				-.03453***	-.03184***	-.03344***
(quakes)				(.01046)	(.01072)	(.01059)
s_3					-.02810	-.03913
(quakes)					(.02612)	(.02834)
s_4						.05452
(quakes)						(.05784)
Adj. R-squared	.05959	.06192	.09232	.13762	.15406	.17512
p-value(quakes)	.263	.348	.681	.008	.011	.009
p-value(cyclones)	.000	.000	.000	.000	.000	.000
Propensities	yes	yes	yes	yes	yes	yes
FE	country	country	country	country	country	country
Observations	5,171	5,171	5,171	5,171	5,171	5,171

Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. The results are shown omitting the coefficients for propensities to be affected and fixed effects. Robust standard errors are reported in parentheses.

Table T6: Predicting declared losses - earthquakes only

Specification (S) - hypothetical first stage

VARIABLE	**Annual damages declared in EM-DAT (% GDP)**					
Energy×density	-.00000					
(cyclones)	(.00004)					
s_0		-.00002	-.00002	-.00002	-.00002	-.00002
(cyclones)		(.00018)	(.00023)	(.00023)	(.00023)	(.00023)
s_1			-.00002	-.00007	-.00005	-.00002
(cyclones)			(.00046)	(.00064)	(.00067)	(.00067)
s_2				.00009	-.00006	-.00012
(cyclones)				(.00098)	(.00140)	(.00140)
s_3					.00025	.00030
(cyclones)					(.00148)	(.00160)
s_4						-.00015
(cyclones)						(.00326)
Energy×density	.00042***					
(quakes)	(.00004)					
s_0		.00120***	.00103***	.00104***	.00103***	.00103***
(quakes)		(.00010)	(.00016)	(.00016)	(.00017)	(.00017)
s_1			.00083	.00044	.00033	.00028
(quakes)			(.00062)	(.00089)	(.00090)	(.00090)
s_2				.00157	.00097	.00095
(quakes)				(.00252)	(.00261)	(.00261)
s_3					.00561	-.00442
(quakes)					(.00636)	(.00698)
s_4						.04937***
(quakes)						(.01425)
Adj. R-squared	.02283	.02289	.02285	.02253	.02230	.02427
p-value(quakes)	.000	.000	.000	.000	.000	.000
p-value(cyclones)	.943	.888	.990	.999	.999	1.000
Propensities	yes	yes	yes	yes	yes	yes
FE	country	country	country	country	country	country
Observations	5,171	5,171	5,171	5,171	5,171	5,171

Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. The results are shown omitting the coefficients for propensities to be affected and fixed effects. Robust standard errors are reported in parentheses.

Table T7: Influence of direct losses on domestic production - cyclones only

Specification (S) - second stage

Panel A						
VARIABLE	**First difference of output growth $y_t - y_{t-1}$**					
Damages (% GDP) d_t	-0.052	-0.305	-0.554*	-0.472***	-0.449***	-0.450***
	(0.041)	(0.362)	(0.305)	(0.138)	(0.138)	(0.110)
Instruments	-	s^c_0	$s^c_{0,1}$	$s^c_{0,1,2}$	$s^c_{0,1,2,3}$	$s^c_{0,1,2,3,4}$
Controls	-	-	-	-	-	-
Propensities	yes	yes	yes	yes	yes	yes
Observations	5,098	5,098	5,098	5,098	5,098	5,098
Panel B						
VARIABLE	**First difference of output growth $y_t - y_{t-1}$**					
Damages (% GDP) d_t	-0.050	-0.047	-0.454*	-0.455***	-0.445***	-0.447***
	(0.105)	(0.298)	(0.247)	(0.101)	(0.095)	(0.096)
Instruments	-	s^c_0	$s^c_{0,1}$	$s^c_{0,1,2}$	$s^c_{0,1,2,3}$	$s^c_{0,1,2,3,4}$
Controls	yes	yes	yes	yes	yes	yes
Propensities	yes	yes	yes	yes	yes	yes
Observations	3,986	3,986	3,986	3,986	3,986	3,986
Panel C						
VARIABLE	**Output growth y_t**					
Damages (% GDP) d_t	-0.130**	0.059	-0.114	-0.180	-0.200*	-0.223**
	(0.054)	(0.140)	(0.126)	(0.110)	(0.103)	(0.101)
Instruments	-	s^c_0	$s^c_{0,1}$	$s^c_{0,1,2}$	$s^c_{0,1,2,3}$	$s^c_{0,1,2,3,4}$
Controls	yes	yes	yes	yes	yes	yes
Propensities	yes	yes	yes	yes	yes	yes
Observations	3,986	3,986	3,986	3,986	3,986	3,986

Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. Declared losses are annual losses from wind-based events divided by current GDP. The results are shown omitting the coefficients for propensities to be affected, fixed effects and controls: gross capital formation, government consumption, total reserves, current account, domestic credit, imports, FDI inflows and GDP per capita. Standard errors are clustered at country level. The specifications are simple 2SLS in panels A and B and Arellano-Bond difference GMM estimator with one lag in panel C.

Table T8: Descriptive statistics: measures of annual exposure

Sample	Mean						observations
Cyclones	s_0	s_1	s_2	s_3	s_4	s_5	total: 5143
$s_0 > 0$	.545	-	-	-	-	-	660
$s_1 > 0$	.719	.293	-	-	-	-	362
$s_2 > 0$	.915	.403	.217	-	-	-	191
$s_3 > 0$	1.10	.499	.288	.163	-	-	113
$s_4 > 0$	1.14	.570	.379	.269	.157	-	35
$s_5 > 0$	.783	.396	.215	.181	.113	.031	4
Earthquakes	s_0	s_1	s_2	s_3	s_4	s_5	total: 5143
$s_0 > 0$	.343	-	-	-	-	-	1478
$s_1 > 0$	.448	.102	-	-	-	-	986
$s_2 > 0$	.476	.114	.030	-	-	-	691
$s_3 > 0$	.447	.103	.027	.007	-	-	474
$s_4 > 0$	.463	.101	.025	.007	.003	-	303
$s_5 > 0$	.897	.230	.063	.015	.003	.001	24

Average measures of exposures on different samples of country/year observations (when $s_0 > 0$, $s_1 > 0$...). Only cyclones and earthquakes between 1980 and 2006 are considered. The indices (s_n) represent the annual proportions of the population exposed to category 0, 1, 2, 3, 4, 5 cyclones and Mercalli scales of IV, V, VI, VII, VIII and IX for earthquakes.

Table T9: Descriptive statistics: the profile of affected countries

VARIABLES	**Unaffected**	**Cyclones only**	**Earthquakes only**	**Cyclones and earthquakes**
Countries	91	46	34	39
Population ('000 000, 2006)	1'019	1'016	414	4'056
GDP per capita (2006)	14737	9496	15584	7297
Private credit (% GDP, 2006)	43.43	54.80	79.11	57.36
Agriculture (% GDP, 2006)	14.51	15.76	12.24	11.63
Manufacture (% GDP, 2006)	13.42	13.11	13.00	15.74
Industry (% GDP, 2006)	34.77	30.18	25.93	28.78
Reported losses (cyclones, % GDP, 1980-2006)	0	0	7.70	4.64
Reported affected (cyclones, % pop., 1980-2006)	0	0	3.01	5.05
Affected (cat. 2 cyclones, % pop., 1980-2006)	0	0	57.52	56.29
Affected (cat. 4 cyclones, % pop., 1980-2006)	0	0	12.66	3.12
Reported losses (quakes, % GDP, 1980-2006)	0	0.48	0	0.26
Reported affected (quakes, % pop., 1980-2006)	0	1.22	0	0.40
Affected (VI quakes, % pop., 1980-2006)	0	14.64	0	36.67
Affected (VIII quakes, % pop., 1980-2006)	0	0.96	0	0.91

Only cyclones and earthquakes between 1980 and 2006 are considered. The indices (s_n) represent the annual proportions of the population exposed to category 0, 1, 2, 3, 4, 5 cyclones and Mercalli scales of IV, V, VI, VII, VIII and IX for earthquakes.

Table T10: Example of catastrophes, reports and objective indicators of exposure

	Country/Year		Reports		Obj. measures		
Earthquakes	Country	Year	Losses	Affected	Thresholds		
					V	VII	VIII
	Pakistan	2005	.218	.033	.101	.014	.001
	Japan (Kobe)	1995	.019	.004	.649	.100	.017
	Salvador	2001	.112	.223	6.89	.293	.038
	Chile (Santiago)	1985	.091	.122	7.01	.343	.112
Cyclones	Country	Year	Losses	Affected	Thresholds		
					1	3	5
	US (Katrina)	2005	.010	.002	.106	.007	.001
	US (Andrew)	1992	.008	.006	.152	.034	.004
	Honduras (Mitch)	1998	.729	.353	.919	.025	.001
	Japan (Songda)	2004	.002	.000	.476	.109	.005

Only cyclones and earthquakes between 1980 and 2006 are considered. Losses are indicated as a ratio of GDP. The affected population is computed relatively to the total population. The thresholds index n represent the proportion of the population exposed to a cat. n event for cyclones and Mercalli scales of V, VII and IX for earthquakes.

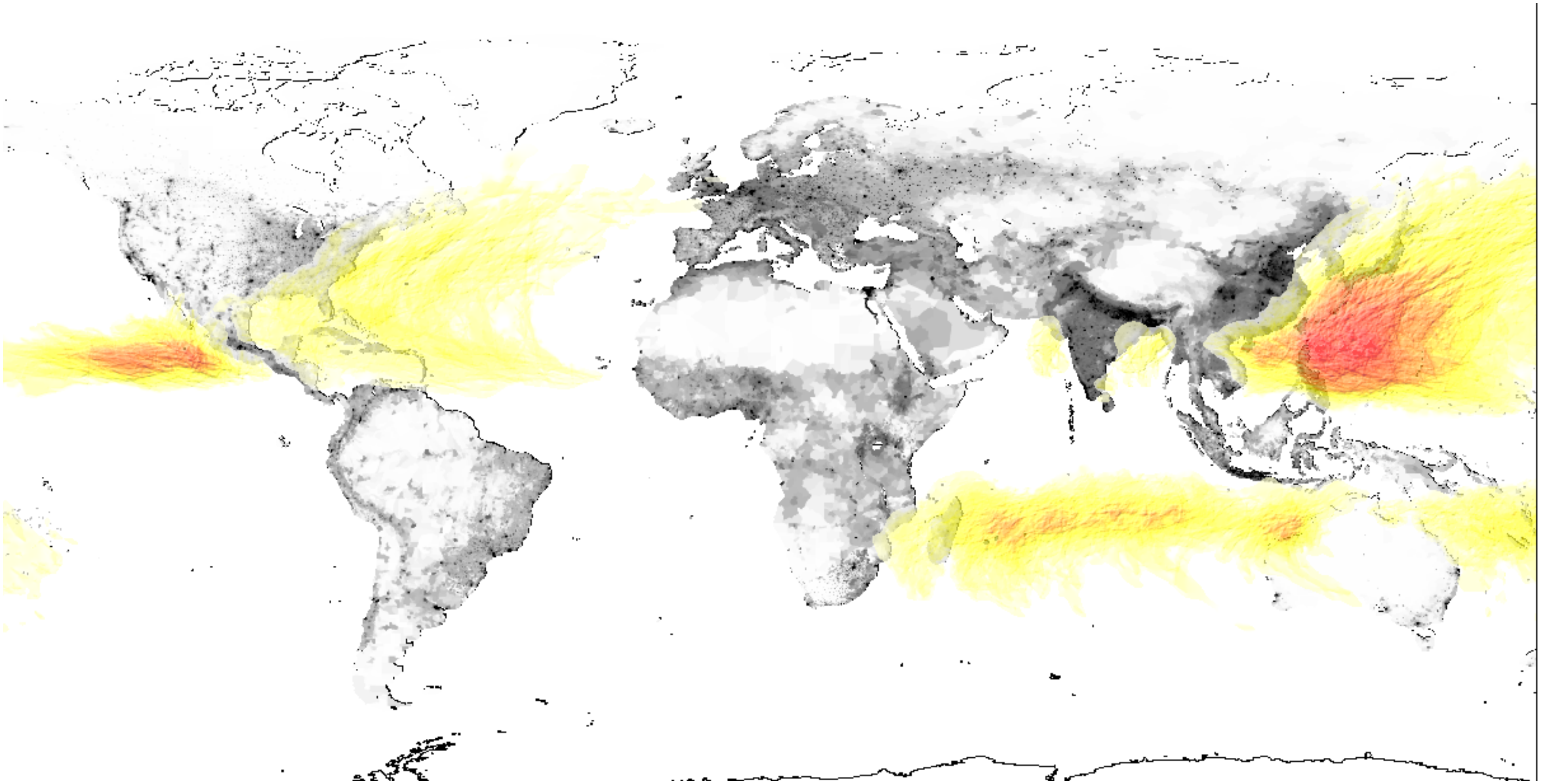


Figure F2: Tracks of cyclones since 1980 and density as of 2000

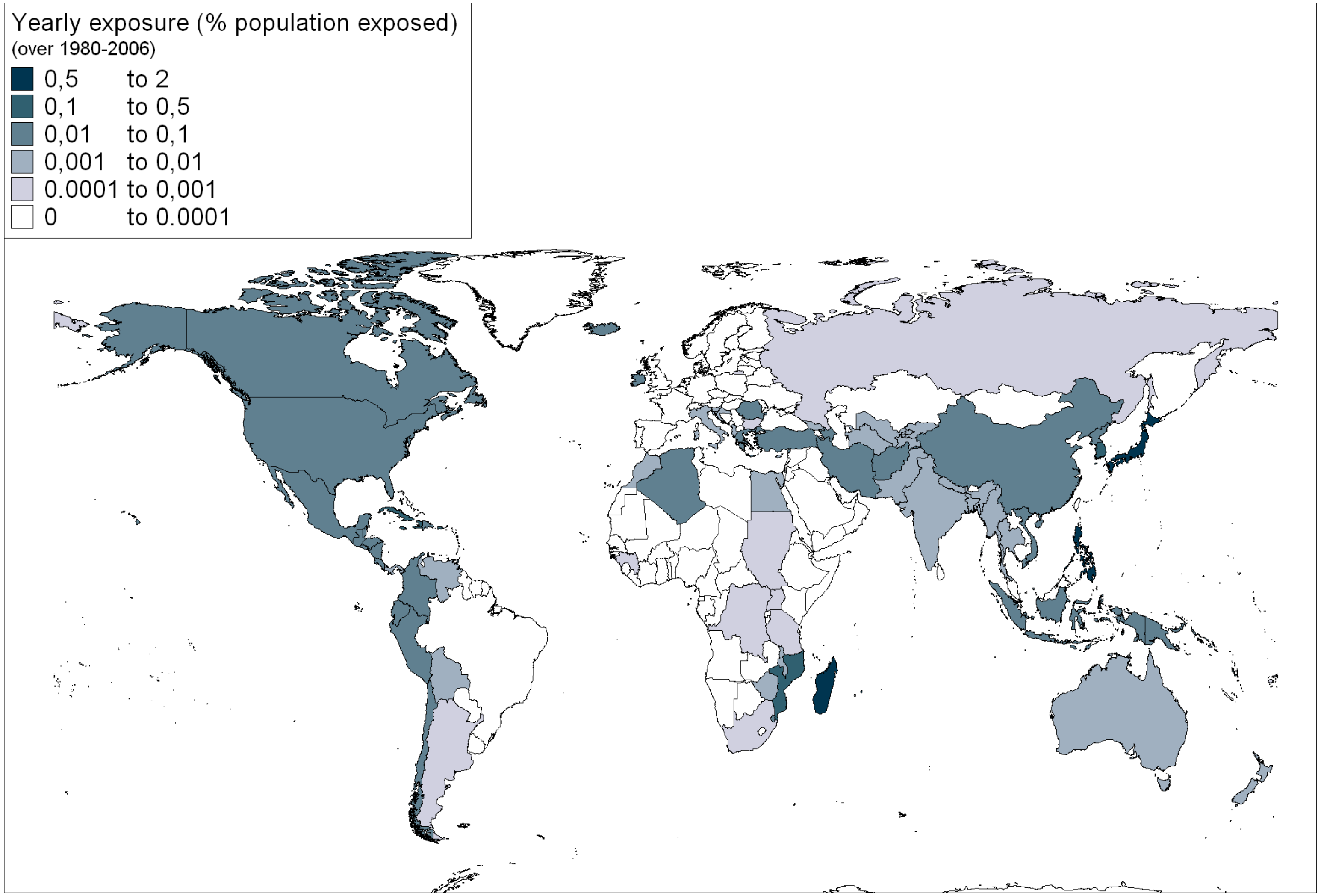


Figure F3: Exposure to cyclones and earthquakes between 1980 and 2006