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JEL Codes: O13, Q51, Q54

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Natural natural disasters and economic disruption

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Abstract

The cost of natural calamities is not limited to direct damages and immediate material costs. Economies in the wake of severe shocks experience important slowdowns and long business disruptions. I construct a unique dataset of objective measures on cyclones and earthquakes between 1980 and 2006 and complement existing reports on direct damages. I then estimate the amplitude of indirect economic losses in the aftermath of catastrophes. Declared damages accounting for 1% of GDP translate into a slowdown of .05 to .06 points of GDP growth. The results are essentially driven by cyclones; earthquakes having no effects on immediate growth rate. When instrumenting by the actual exposure, this elasticity piles up to .4. This observation points out censorship issues regarding declarations of losses. In addition, the objective measures happen to be better at predicting the economic slack than reports from officials.

Keywords: Natural disasters, economic disruption, declaration biases.

JEL classification: O13, Q51, Q54

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I. Introduction

The impact of natural disasters on economic indicators 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. Thus, few economic studies have evaluated the amplitude of propagation of initial tremors to the rest of the economy. 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.

Relying on a unique dataset, 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. Direct losses of \$ 1 echoed on economic activity with GDP losses of 40 cents following cyclones. Earthquakes do not seem to be accompanied by strong repercussions. Nevertheless, the negative spillover seems to fade away one year later, leaving the economy close to the pre-disaster growth path. The difference between seismic aftermaths and cyclones consequences can be explained by different initial environment for affected economies. As highlighted by Noy [2009], financial conditions might alleviate the pressure imposed on the economy by important capital losses and counteract for the potential negative spillovers.

The literature on macroeconomic consequences of natural disasters has roughly followed two leads. While Albala-Bertrand [1993] and Noy [2009] have tried to estimate directly the effect of calamities on aggregate production, Gassebner *et al.* [2006], Rasmussen [2004] or Skidmore & Toya [2002] have tried to study the responses from some components of the economy more closely. Gassebner *et al.* [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 & 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. Accounting for these different effects, it seems difficult to extract a clear trend on the aggregate domestic production. Nevertheless, contradicting a seminal and mostly descriptive paper (Albala-Bertrand [1993]), Noy [2009] 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.

These articles on natural disasters in the economic literature have mainly relied on reported losses rather than objective measures to assess how an economy might be affected by a catastrophe. As such, their estimations rely on the fact that shocks recorded in their dataset reflect effective losses and are not correlated with some other unobserved variables which might affect the dependent variable, let us say, the outcome or one of its component. As emphasized by Rosenzweig & Wolpin [2000], few experiments can be considered as perfect natural experiments. This article alleviates three stumbling blocks which might bias the results or their interpretation when considering the aftermath of natural disasters. First, natural disasters are unpredictable in the sense that an occurrence can never be announced with 100% confidence before it occurs. It does not mean that institutions designed to mitigate natural disasters do not account for the probability of an occurrence and potential losses. 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. Not controlling for potential exposure, the differential impact on risky zones and riskless ones might bias the results and overweight the responses of highly exposed economies. Second, 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. As a consequence, relief and post-shock management have both a large influence on the level of damages for these long-lasting events. Furthermore, the causal link between post-shock management and the amplitude of direct losses is not clear. Brückner et al (2010) relate droughts and regime switches in Africa showing that droughts reveal the type of a regime and its ability to provide self-therapy. In this project, I focus on sudden events offsetting partly the influence of access to international assistance and governance on **direct** losses. Third, losses are not completely verifiable. This feature is extremely important and explains the absence of formal private and public insurance. As such, the datasets reporting direct damages are censored and entries might be biased downward or upward depending on the returns expected from signaling an important vulnerability or a good recovery. These biases are not completely tackled by the papers cited above. 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 poor-institutionalized countries. Ramcharan [2007] tries to evaluate the interest of having fixed rate against flexible exchange rate regims using reports on natural shocks as instruments. Flexibility helps recover from a natural disaster. However, if fixed exchange rate is used in countries with low governance capacities, which in turn might induce low self-therapy or inflating reports, the exclusion hypothesis is violated. This article puts forward an additional measure to the reported damages for estimating direct losses and mitigating declaration biases.

To my knowledge, this paper is the first paper of this literature trying to identify the amplitude of economic disruption using an objective dataset of large and sudden catastrophes. This paper also makes interesting methodological contributions by establishing the predictive power of such measures. Surprisingly, they not only are powerful predictors for reports on direct damages but also perform better at determining the degree of ex-post economic slowdown than the latter.

I present in section II. the construction of the dataset and some features of the

measures. Then, I discuss the empirical strategies and identifying hypotheses in section III.. In section IV., I present three specifications induced by the previous section and estimations of income losses due to the passage of typhoons and earthquakes. Extended results using these specifications are discussed in section V., focusing on a potential catching-up effect two years later.

II. Construction of natural shocks

A. Data description

From Joint Typhoon Warning Center and PREVIEW Global Cyclones Asymmetric Wind speed Profile, I extract best tracks of tropical typhoons, cyclones and hurricanes between 1980 and 2006. These data is composed of the tracks and wind profiles of cyclones and tropical typhoons having been 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). These data has been collected and modified by UNEP/DEWA/GRID-Geneva and represent a quasi-exhaustive map of cyclones and typhoons having formed in the Atlantic basin, North and South Indian basins, Australian basin and West and East Pacific basins (in total, the datasets regroup 1866 events, only few of them having landed though). Wind intensity, pressure, precise location, form and size of the eye are precisely documented every 6 hours. I then construct the local dissipated energy along the path of the cyclone. To control for the potential exposure to such events, I use the Global Cyclone Hazard Frequency and Distribution data and assess precisely the exposure profile of any area in the world¹.

The earthquakes studied here are extracted from Earthquake catalogs produced by the USGS and National Geophysical Data Center. As such, the database goes from 1965 to 2006 but 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

¹the data associates the exposure profile computed between 1980 and 2000 for 'squares' whose dimensions are roughly 0.25 degree of latitude and 0.25 degree of longitude.

date, the position of the epicenter and the depth. From these tracks, it is possible to reconstitute the sum of all hazard realizations (approximately 20000 measured events with a magnitude above 5) providing a good idea of potentially affected regions. Similarly than for cyclones, Global Cyclone Hazard Frequency and Distribution data complements the data on tremors by giving characteristics on faults and geological composition for a grid of 0.25 degree of latitude and 0.25 degree of longitude.

The data about population densities is extracted from the Gridded Population of the World project created by the Center for International Earth Science Information Network (CIESIN), Columbia University and Centro Internacional de Agricultura Tropical (CIAT). 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 figure F1 shows Asia and Europe in 2000.

The EM-DAT² database represents the most complete public database on natural disasters, listing approximately 9300 catastrophes since 1968, of which 780 earthquakes, 470 droughts, 3000 floods, 2600 wind storms. Apart from the nature of the catastrophe, the location and exact time of its occurrence, EM-DAT gives also the associated disasters in the aftermath of the first shock, the criterion on which the EM-DAT team has selected this particular catastrophe³, the number of people affected, homeless, injured or killed, the economic damages, the insured damages, the aid contribution, indicators of magnitude if any, the potential request for international assistance... The selection process might be influenced by endogenous factors particularly when the trigger is a declaration of emergency (a country where the immediate relief is completely inefficient might want to conceal this state failure to potential partners and thus might fear international assistance) and the data are often truncated when it comes to economic or human damages. As for the economic indicators, they are mostly extracted from World Development Indicators, Penn

²EM-DAT: The OFDA/CRED International Disaster Database (www.emdat.be), Université Catholique de Louvain.

³this criterion still 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.

World table and Global Development Finance.

B. Data construction

The objective of the construction is to supply a local measure of economic impact generated by a disaster controlled by the local expected threat. To account for the potential natural threat, I rely on a measure of the energy dissipated in a certain area. As it is not possible to derive exactly the pressure exerted by a typhoon or an earthquake on buildings, infrastructures, crops, the energy dissipated is the best alternative to estimate potential economic direct damages leaving aside transmission mechanisms. Concerning cyclones, Bister & Emanuel [1998] and Emanuel [2005] proposes a measure locally proportional to the cube of wind speed.

$$P = C_d \rho v^3 \tag{P}$$

Assuming that the drag coefficient and the air mass density are constant along the path of the cyclone, the formula above sums up to:

$$E_d = \int \int C_d \rho v^3 d\tau dS \tag{Ed}$$

For earthquakes, works initiated by Hanks & Kanamori [1979] to replace the Richter scale immediately relate measures of intensity (M_w moment magnitude) with the seismic moment M_0 . 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.

$$E_s = M_0 = 10^{(M_w+b)/a} \tag{Es}$$

The construction will rely on estimates supplied by Choy & Boatwright [1995]. Considering that these constant are uniform over the globe is certainly leading us to misestimate slightly the energy radiated during each earthquake. Notwithstanding, there are no evident biases induced by these approximations. In appendix, I detail

the exact construction of the index and corrections for distance attenuation.

The only local available information on economic activity is the density of population. Building on an analysis of OECD countries, wealth and capital (density d_k) are more concentrated than population (density d_w); on a small area ds :

$$l_k ds = d_p^\sigma E ds$$

As a consequence, capital density exhibits increasing returns to population density. With OECD data on sub-national divisions of population and capital, a 1% increase of population density for a region within a country is associated with a 1.13% increase of capital for this region. The degree of immediate capital losses depends locally on the energy dissipated E and the local density of capital. Intuitively, this functional form supposes that direct losses are proportional to exposed capital. As such, the possibility that overcrowded areas might be also over-exposed is here ruled out. Nonetheless, this intuition can be captured by a function f showing increasing returns to scale. Assuming that a linear relationship should exist between these energy and the proportion of assets which might be destroyed during the passage of a typhoon or during a tremor is a constraint I impose on the model. Nevertheless, relaxing this assumption does not provide significant improvement on the predictive power of the index developed here.

Economic activity in disaster-prone areas has no reason to be similar than in safe areas. Despite little evidence on systematic mitigation by leaving disaster-prone areas, it is reasonable to think that security norms might be tighter in disaster-prone areas. Under this assumption, an omitted-variable bias would arise, leading us to 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, the omitted-variable bias would artificially distort the importance of natural disasters as most frequent disasters occurs in places where unobserved mitigation is the weakest.

I will assume that agents are perfectly informed⁴ about the expected natural

⁴it is possible to extend this hypothesis to the following: agents share the same information in

threat they are facing by living in a certain area. As such, under the stationarity of the distribution, the expected distribution would be approached with a "sufficient" number of observations by the empirical distribution of natural threat. Typhoons and earthquakes are rare events. As such, it might be necessary to extend the empirical distribution using continuity arguments for the expected distribution so as to improve the estimated distribution or to rely on other signals than past realization. As complement, I use first a project Global Seismic Hazard Assessment Program initiated in the framework of the United Nations International Decade for Natural Disaster Reduction. This program provides a measure of the probability for a fault to awaken based on geological observations rather than past realizations. Second, I disturb randomly the past tracks and compute the predicted losses associated with the fictional trails. This construction allows to create additional events, potentially reducing the distance between the empirical past exposure and the effective exposure. In the case of cyclones, as their occurrences are undoubtedly related to Sea Surface Temperature, the stationarity of the distribution over time is not obvious. This feature has already been highlighted by Emanuel [2005]. This study will not allow any differential evolution of the exposure between different regions. Even though this assumption might be theoretically restrictive, it is plausible that economic agents do not anticipate any differential effect of climate change on cyclones occurrence⁵.

C. Overview

The figure F2 and F3 show the geographic dispersion of affected countries for both cyclones and earthquakes. Earthquakes essentially occur along the faults that exist between tectonic plates. Some earthquakes occur away from the plate boundary. However, 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 (United States, Central America, Chile, Ecuador, zones with similar expected natural threat.

⁵the scientific controversy only stick to the question of climate change and frequency of cyclones. Even when limited to this issue, the results suffer from lack of data.

Bolivia...) 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). The dataset cover almost 100 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 T2 documents countries having the highest exposure to raw natural threat and once controlled by the demographic dispersion. The medals' table reward 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 T4 presents the worst⁶ catastrophes in our surveyed window (1980-2006). As expected, Katrina and Kobe's earthquakes are the costliest events during this period. Nonetheless, this also shed light on the particular case of island-countries and overcrowded Central America countries. Relatively to the size of their economy, Ecuador (earthquake, 1987), Grenada (hurricane Ivan, 2004) and Saint-Kitts and Nevis (hurricane Luis, 1998) for example underwent direct losses larger than 10% of their domestic annual production. Even though most of the reported damages were capital losses, part of this shock should appear on the growth path of the country. The events evoked above illustrate several channels through which domestic production can be affected.

The 1987 earthquake in Ecuador has unquestionably frozen some economic sectors of Ecuadorian production. The Trans-Ecuadorian pipeline has suffered from major damages. Given the importance of oil fields in Ecuadorian exports, this contributed to a quick deterioration of foreign debt levels. Similarly, the destruction

⁶in absolute and relative terms.

of bridges isolated a part of the farmers in Napo province from the crop market, leading to production losses. By comparison with this calamity, the passage of Luis (a category 4 hurricane) in Saint-Kitts and Nevis was far less dreadful. Nonetheless, without dwelling on the details, this agricultural economy suffered from important crop losses and the water system underwent severe damages. As for the example of Grenada and Ivan (a category 5 hurricane), the destruction of the residence of the prime minister and a prison allegedly added to the chaos in the aftermath. Uncertainty about immediate relief gave the incentives for local population to find relief by themselves. Looting has certainly contributed to the economic losses to a large extent. Figure 1 emphasizes the economic disruption in the three cases evoked here. Grenada and Ecuador present a classic GDP profile with a large disruption absorbed after one year, once smoothed the distortions induced by the catastrophes. On the opposite, losses in t are small in the case of Saint-Kitts and Nevis.

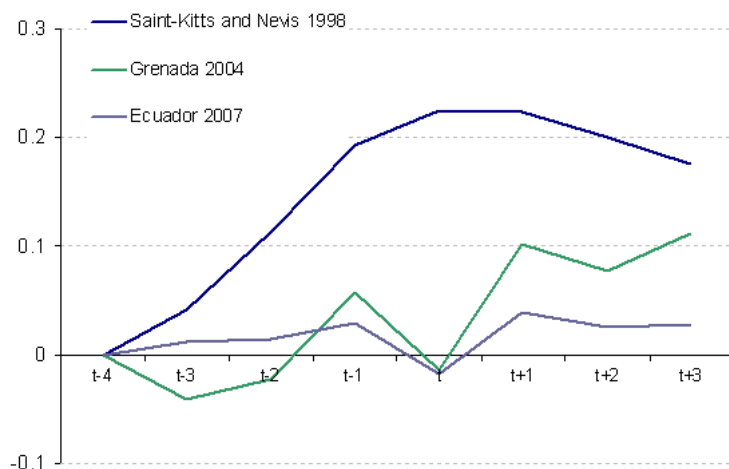


Figure 1: Some examples of economic disruption (GDP normalized to 0 in $t - 4$)

It may be noted that some instruments could alleviate the aftermath of a natural disaster. Insurance, aid contributions and debt rescheduling might provide immediate ex-post resources. Insurance is almost absent in the subsample of developing and under-developed countries. As for developed countries and established risk, since 2000, insured damages account for respectively 40% and 15% of losses due to typhoons in Japan and earthquakes in United States. Furthermore, insurance concerns mainly capital losses and does not mitigate losses from business disruption.

tion. International assistance likewise provides funds focusing mainly on immediate relief than reconstruction or economic upturn. The amounts specified in EM-DAT are negligible except for very few events⁷. Accordingly, countries in the wake of a shock rely first and foremost on reserves, debt relief or suspension of external debt payment and austerity plans.

III. Empirical strategies

To assess the amplitude of the economic slowdown following a year t marked by a natural disaster c for a country i , I assume a linear relationship between the level of annual direct damages D_t^i and the indirect downturn in domestic production $\delta Y_t^i = Y_t^i - E[Y_t^i | D_t^i = E[D_t^i]]$. Considering that transmission mechanisms α do not differ between countries,

$$\delta Y_t^i = \alpha (D_t^i - E[D_t^i])$$

Dividing by previous domestic production and linearizing,

$$y_t^i = \alpha^i (d_t^i - E[d_t^i]) + E[y_t^i | d_t^i = E[d_t^i]]$$

Two measures might capture the level of annual direct damages. First, declarations of damages reported in EM-DAT allow to construct the sum of declared direct losses for a country during the ongoing year. Second, the annual energy dissipated corrected by the density could be a good indicator of the amplitude of immediate economic losses. Let us consider C_t^i the set of catastrophes occurring at any time during the year t and affecting country i .

$$\begin{cases} dd_t^i = \sum_{c \in C_t^i} dd^i(c) \\ de_t^i = \sum_{c \in C_t^i} Ed^i(c) \end{cases}$$

For a given country, cyclones often occur in a small window of two to three months. As such, controlling for the number of months the business disruption might have

⁷Haïti (2009) and the tsunami of December 2004 are exceptions in this matter.

put a strain on the economy is not as crucial as for earthquakes. For the latter, I weight each catastrophe by the number of months for which they could have affected ongoing production. Finally, from data on potential exposure, we can consider the expected dissipated energy interpolated with density pde_t^i as a good indicator of annual expected direct losses.

Let us examine now how the counterfactual $\tilde{y}_t^i = E[y_t^i | d_t^i = E[d_t^i]]$ can be accounted for. Two different approaches are here privileged. In the first instance, a broad set of controls X_{t-1} in $t - 1$ might prove sufficient to capture this counterfactual.

$$E[y_t^i | d_t^i = E[d_t^i]] = \zeta y_{t-1} + \beta X_{t-1} + \varepsilon_t^i$$

Finally, so as to account for evolution of some variables explaining the growth of domestic production, we can consider the same model with macroeconomic indicators as of date t . Nonetheless, it imposes instrumenting by past realizations X_{t-1} so as to control for reverse causality (effect of domestic production on X_t). This process ensures consistent identification as long as y_{t-1}^i contains the whole information at $t - 1$: $E[\tilde{y}_t^i | y_{t-1}^i] = E[\tilde{y}_t^i | X_{t-1}^i, y_{t-1}^i]$.

To sum up, reintroducing direct losses, two models might be tested:

$$y_t^i = \alpha d_t^i + \alpha_e pde_t^i + \zeta y_{t-1} + \beta X_{t-1} + \varepsilon_t^i$$

and

$$\begin{cases} X_t = \psi(X_{t-1}, y_{t-1}, d_t^i, pde_t^i) + \nu_t & (s_1) \\ y_t^i = \alpha d_t^i + \alpha_e pde_t^i + \zeta y_{t-1} + \beta \hat{X}_t + \varepsilon_t^i & (s_2) \end{cases}$$

Up to this point, the issue of a potential endogeneity bias introduced by relying on declarations has not been tackled. 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. The level of expected growth might change the expected returns to signaling a certain level of losses and thus impact

the measure of direct damages. 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 both declared losses and energy-proxies are not correlated to unpredicted growth of domestic production, the following models are identified whether $d_t^i = dd_t^i$ or $d_t^i = de_t^i$,

$$y_t^i = \alpha d_t^i + \alpha_e pde_t^i + \rho y_{t-1} + \beta X_{t-1} + \varepsilon_t^i \quad (S1)$$

and

$$\begin{cases} X_t = \psi(X_{t-1}, y_{t-1}, d_t^i, pde_t^i) + \nu_t & (s_1) \\ y_t^i = \alpha d_t^i + \alpha_e pde_t^i + \zeta y_{t-1} + \beta \hat{X}_t + \varepsilon_t^i & (s_2) \end{cases} \quad (S2)$$

Relaxing the hypothesis that declared losses and unpredicted growth are not correlated but still relying on the hypothesis that once controlled by predicted exposure, physical exposure is uncorrelated to unpredicted growth:

$$\begin{cases} \begin{pmatrix} X_t \\ dd_t^i \end{pmatrix} = \Psi(X_{t-1}, y_{t-1}, d_t^i, pde_t^i) + \nu_t & (s_1) \\ y_t^i = (\alpha, \beta) \begin{pmatrix} \hat{X}_t \\ dd_t^i \end{pmatrix} + \alpha_e pde_t^i + \zeta y_{t-1} + \varepsilon_t^i & (s_2) \end{cases} \quad (S3)$$

The identification method relies on a two step process. First, the declared losses and the other macroeconomic variables are predicted respectively by the energy-density index and past realizations. The second step is the estimation of the transmission of direct damages into indirect economic losses. As the energy-density index is computed using past density and the occurrences of typhoons and earthquakes, it is unlikely correlated with unpredicted growth conditional on the value of declared damages. In other words, this index is a very good instrument as long as it can predict the amplitude of declared losses. An important restriction of those three specifications is that they impose a constant transmission parameter, leaving aside the possibility that economies might differ in their ability to recover from severe capital shock.

Table 1: Hypothetical first stage

Specifications	First stage			
	Declared damages			
	All catastrophes		Cyclones and quakes	
	OLS		OLS	
Energy index (q)	-.000 (.009)	-.003 (.009)	-.000 (.009)	-.008 (.008)
Energy-density index (q)		.039 (.009)**		.118 (.009)**
Energy index (c)	-.006 (.009)	-.005 (.009)	.000 (.009)	-.012 (.009)
Energy-density index (c)		.267 (.034)**		.296 (.033)**
Propensity (q)	-.002 (.013)	-.002 (.014)	.000 (.009)	-.000 (.013)
Propensity (c)	.048 (.018)**	.035 (.019) [†]	.073 (.018)**	.058 (.018)**
Observations	4520	4520	4520	4520

Significantly different than zero at [†] 90% confidence, * 95% confidence, ** 99% confidence. The observations are here country/year. Index are thus the sum over the year of the energy and energy-density index for each catastrophe. The results are the same with country fixed effects.

IV. Amplitude of economic disruption

Before analyzing the effect of direct losses on domestic production, let us establish the power of physical measures at predicting declared losses. As shown in table T3 in the appendix, the energy-density index performs far better than magnitude or maximum wind speed. An additional standard deviation of energy dissipated⁸ generates additional 3% losses for earthquakes and 27% for cyclones⁹. These first results are confirmed by the hypothetical first stage reported in table 1. The observations are then country/year and I compare aggregate declared damages to the

⁸interpolated with density.

⁹the relatively weak correlation for earthquakes reflect essentially difficulty in matching events with all the associated tremors. These difficulties fade away when aggregating the energy over the year for a country.

constructed index for a country over the year. The fact that unweighted annual dissipated energy does not predict declared damages in any of the specifications tends to emphasize the role of local density weights. Focusing on the last specification and the density-weighted index, an increase of 1 standard error for the annualized energy-density index increase annualized declared damages by .118 standard deviation for earthquakes and .296 for cyclones. These figures translates respectively into 1 and 2.4 points of GDP growth. The hypothetical first stage give credits to the use of physical index as instruments for direct damages as reported by officials, as they predict extremely well these reports.

Table 2: Influence of direct losses on domestic production

		Second stage							
		GDP growth (t)							
		(S1)		(S2)		(S3)		(S3)	
		All	Cyc.	All	Cyc.	All	Cyc.	All	Cyc.
Declared losses		-.050 (.025)*	-.034 (.021)	-.045 (.025) [†]	-.035 (.021)	-.400 (.321)	-.342 (.204) [†]	-.421 (.325)	-.371 (.205) [†]
GDP growth (t-1)		.328 (.015)	.325 (.015)	.334 (.017)	.331 (.016)	.339 (.018)	.335 (.017)	.337 (.019)	.341 (.018)
Propensity (q)		-.011 (.029)		.003 (.029)		.003 (.030)		.027 (.031)	
Propensity (c)		-.019 (.009)*	-.009 (.008)	-.017 (.009) [†]	-.006 (.007)	-.014 (.010)	.000 (.009)	-.013 (.010)	-.005 (.010)
Controls		C_1		C_1		C_1		C_2	
Observations		3193	3384	3133	3320	3133	3320	3040	3196

Significantly different than zero at [†] 90% confidence, * 95% confidence, ** 99% confidence. The dependent variable is the GDP growth for the ongoing year. Declared losses are annual losses divided by current GDP. The set of controls C_1 groups gross capital formation, government consumption, total reserves and current account. Additionnally to these variables, the set C_2 includes domestic credit, imports, FDI inflows and GDP per capita. The results are robust to the addition of country fixed effects and time fixed effects. The simplest specifications are displayed here.

The first and direct estimations concerning the effect of direct losses on domestic production shows that economies face a slowdown in the aftermath of calamities.

Thus, as shown in table 2, reported losses of 1 point of GDP yield a slack accounting for approximately .05 of GDP growth, .03 when focusing on cyclones. The results are robust to the addition of country or time fixed effects and other controls than those used in C_1 . They are also invariant using specification (S_2). Nonetheless, this robustness does not give support to the exogeneity of declared damages. First, the results are substantially lower than without propensity measures¹⁰. Second, 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. Despite being only slightly significant at 10% for cyclones and non significant for both cyclones and earthquakes together, the indirect losses climb up to roughly 40% of the initial capital losses. Incidentally, these results are robust despite being hardly significant. Seeing the glass as half-empty, the coefficient is robustly non-different from zero at a 5%-confidence interval. The half-full-glass side would point out that the results are remarkably stable through the different specifications.

Let us detail the composition of the basic C_1 and extended C_2 sets of controls composing X_t . 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 capacities¹¹. Current account and government consumption reflect also potential budget shock. Additionally to this basic set, C_2 includes domestic credit so as to capture credit constraints, level of exports, imports, foreign debt and foreign direct investment inflows to account for external shock.

Not only physical exposure is a good instrument, but also simply a good predictor

¹⁰without controlling by propensity to be struck by the catastrophe, direct losses of 1 point of GDP yield a slack accounting for approximately .08 of GDP growth for all catastrophes, .05 for cyclones. Both coefficients are significant at .1%.

¹¹Unsurprisingly, these controls are pro-cyclical.

Table 3: Influence of natural disasters on domestic production - comparing indicators

Specification (S2)						
GDP growth (t)						
	Earthquakes			Cyclones		
Declared losses (q)	-0.005 (.025)		.006 (.032)			
Energy-density index (q)		-0.0027 (.0044)	-0.0033 (.0054)			
Declared losses (c)				-0.035 (.021) [†]		-0.031 (.021)
Energy-density index (c)					-0.0040 (.0019)*	-0.0037 (.0019) [†]
GDP growth (t-1)	.308 (.017)	.308 (.017)	.308 (.017)	.302 (.017)	.301 (.017)	.301 (.017)
Propensity (q)	.0004 (.0008)	.0004 (.0008)	.0004 (.0008)			
Propensity (c)				-0.0005 (.0009)	-0.0004 (.0009)	-0.0004 (.0009)
Time fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes
Controls	C_2	C_2	C_2	C_2	C_2	C_2
Observations	3093	3093	3093	3196	3196	3196

Significantly different than zero at [†] 90% confidence, * 95% confidence, ** 99% confidence. The dependent variable is the GDP growth for the ongoing year. Declared annual losses are divided by current GDP. The set of controls C_2 groups gross capital formation, government consumption, total reserves and current account, domestic credit, imports, FDI inflows and GDP per capita. The simplest specifications are displayed here.

of indirect losses independently of declarations. As made explicit in table 3, adding the physical annual exposure offset the predictive power of declared losses. This table allows us to investigate further and confirm that only wind-based events seems to provide results. To sum up, with specification (S_2), earthquakes do not seem to provoke any kind of economic disruption. Comparatively, a production slack of .035 points of GDP echoes an additional standard deviation of annual physical exposure to cyclones. 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. Annual declared losses do not come out

significantly. This differential impact of natural events with same profile (sudden, highly unpredictable...) might put into evidence noticeable differences between those two types of occurrences, from the panel of affected countries¹² to the importance of the aftermath and associated disasters, or simply differences in the distribution of affected agents. As this study is not aimed at going beyond the determination of some interesting descriptive features on natural disasters' aftermath, I will not push forward any interpretation.

Table 4: Catching up with the growth path

Specification (S2)					
Indicators	GDP growth indicators				
	$y_t - y_{t-1}$	$y_{t+1} - y_t$	$y_{t+1} - y_{t-1}$	$y_{t+1} - y_t$ $-(y_t - y_{t-1})$	$(y_{t+1} - y_{t-1})$ $+(y_t - y_{t-1})$
Energy-density index (c)	-.0035 (.0016)*	.0031 (.0018) [†]	-.0003 (.0017)	.0066 (.0029)*	-.0038 (.0027)
Propensity (c)	-.0019 (.0010)*	-.0001 (.0012)	-.0018 (.0011) [†]	.0017 (.0019)	-.0036 (.0017)*
Time-fixed effects	Yes	Yes	Yes	Yes	Yes
Controls	C_2	C_2	C_2	C_2	C_2
Observations	927	880	880	880	880

Significantly different than zero at [†] 90% confidence, * 95% confidence, ** 99% confidence. The results are robust to the addition of controls (external balance, urban population, levels of debt). The simplest specifications are displayed here. Only the countries having experienced a hurricane landfall during the years 1980-2006 are considered here.

V. Catching-up with the growth path?

The previous section has highlighted the presence of an economic slack created by natural disasters and cyclones in particular. Building on the anecdotal stories about Grenada, Ecuador, quick recovery could be expected, but some economic fundamentals might be severely affected and the economy could suffer from a long period of unrest. Saint-Kitts and Nevis exhibits a long slowdown some years after

¹²earthquakes have a relative bias toward developed countries compared to cyclones and some countries with negative shocks are over-represented -Japan would be the perfect example.

the catastrophe, which might be due to orthogonal shocks or to severe damages to irrigation and crops related to the passage of Luis. In this section, I try to describe how well economies represented in the sample catch up with their growth path.

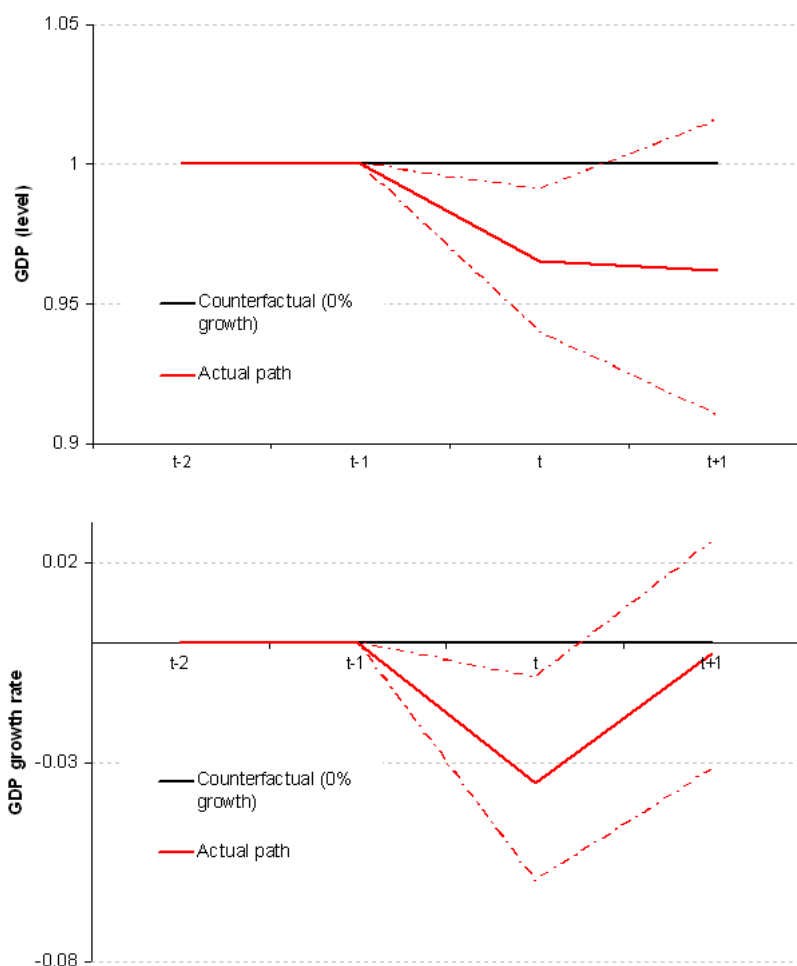


Figure 2: Evolution of GDP and GDP growth rate following a catastrophe (GDP normalized to 1 in $t - 2$)

As reported in table 4, the immediate effect of cyclones on economic production is temporary. As such, the excess growth one year after the shock allows the economy to catch up with the pre-shock level of growth. In other words, the economies are back to the tracks that cyclones forced them to leave. Basically, they retrieve in $t + 1$ their growth level of $t - 1$. Yet, catching-up here does not mean coming close to the counterfactual path (had the country not been affected by the catastrophe).

As such, specifications 2 and 3 tackles the issue of keeping up with the pre-disaster growth rate one period after the shock. An additional standard deviation of

energy dissipated induces an immediate economic slack of .35 points of GDP growth, offset by an excess growth of .31 points one year later. The result for specification 3 confirms that it is not possible to reject the hypothesis that the difference between growth rates in $t + 1$ and $t - 1$ is left unchanged by the catastrophe. Specifications 4 focuses on the amplitude of the mean reversion phenomenon observed here. An additional standard deviation of energy dissipated in t provokes a mean-reversion of .66 points of GDP growth in $t + 1$ relatively to t , carried both by the initial slack and the following recovery. Specification 5 tests the influence of cyclones on the distance between the actual GDP (in level) in $t + 1$ and the GDP had the country kept up with its pre-disaster growth rate. The larger the energy-density index, the further the country seems from its counterfactual path. The impact of cyclones on this measure is non-significant at 10% though. Figure 2 illustrates these results, showing the predicted evolution of GDP following a catastrophe of the amplitude of 10 standard deviations compared to the counterfactual path.

At last, in order to confirm these intuitions, I define a catch-up indicator equal to 1 once the pre-disaster growth path has been caught up. This defines also a the number of years necessary to recover completely. Taking the average growth during the three years before, I construct a *counterfactual path* had the country been unaffected for all country/year. Several issues arise: first, this measure is extremely sensitive to small variations in the definition; second, countries with a volatile growth path will be much more often considered as having recovered; third, it is difficult to affect a value for countries unable to catch at any point in time. For the first and third remarks, I propose additional specifications to show that the results are not completely determined by the definition chosen here. The second issue seems more problematic. Countries recently affected by natural disasters can switch from a relatively non-volatile regime to a high-volatile regime and our definition will overstate the ability of a country to catch up. The results presented in table 5 show Poisson regressions with the same controls as in the previous specifications. The use of a Poisson regression is related to the intuition that countries are in a trap from which they can escape with a fixed exit rate. Naturally, this assumption is restrictive and intuitively hard to justify. It is difficult to capture the idiosyncratic

Table 5: Influence of natural disasters on recovery time

Specification (S2) - Fixed hazard rate						
	Recovery time					
	CR (5 years)		IR (5 years)		CR (10 years)	
	Total					
Energy-density index	.102 (.027)**	.107 (.028)**	.104 (.027)**	.110 (.027)**	.100 (.019)**	.104 (.019)**
Sample	Total	S_t	Total	S_t	Total	S_t
Controls	C_2	C_2	C_2	C_2	C_2	C_2
Observations	2163	1158	2276	1222	2257	1213
	Cyclones					
Energy-density index (c)	.097 (.032)**	.093 (.034)**	.126 (.032)**	.132 (.034)**	.082 (.032)*	.077 (.033)*
Sample	Total	S_c	Total	S_c	Total	S_c
Controls	C_2	C_2	C_2	C_2	C_2	C_2
Observations	2266	662	2387	697	2366	696
	Earthquakes					
Energy-density index (q)	.084 (.052)	.090 (.052) [†]	.066 (.047)	.067 (.047)	.108 (.024)**	.106 (.024)**
Sample	Total	S_q	Total	S_q	Total	S_q
Controls	C_2	C_2	C_2	C_2	C_2	C_2
Observations	2415	1289	2544	1358	2520	1351

Significantly different than zero at [†] 90% confidence, * 95% confidence, ** 99% confidence. The set of controls C_2 groups gross capital formation, government consumption, total reserves and current account, domestic credit, imports, FDI inflows, GDP per capita and propensities to be affected. The simplest specifications are displayed here. The samples S_t , S_c and S_q are respectively countries having been affected by either a cyclone or an earthquake, a cyclone, an earthquake during the considered period (1980-2006). The countries having not recovered within the specified limit (5 or 10 years) are excluded from these samples. CR stands for complete recovery and IR for incomplete recovery. Incomplete recovery is a translation of the complete recovery of 0.5 percentage point downward.

determinants of the hazard rate. As such, the very fact that a country does not exit implies an unobserved weaker propensity to grow in the next periods. Yet, the results establish a positive correlation between the years spent below the growth path and the amplitude of the initial shock. An additional standard deviation of energy dissipated increases recovery time by approximately one month. As shown

in table ??, this result is not entirely due to immediate recovery as accounting for the over-representation of immediate exit does not change the coefficients¹³.

VI. Concluding remarks

This paper has documented how large natural disasters might radiate through the economy and provoke a slowdown of production. 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 study has also shown the predictive power of objective measures, compared to reported losses.

While this article is mainly descriptive, the results encourage us to explore avenues to understand through which mechanisms the first shock radiates and might be offset few months later. Along with this idea, the differential impact between earthquakes and cyclones raises a lot of questions related to those already evoked. Is it due to the very nature of the shock or simply to the characteristics of affected economies? Finally, no 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 a methodology focusing mainly on "non-economic losses".

¹³Natural events following fat-tails distributions, a dozen of events present amplitude at least 10 times higher than this standard deviation.

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A Construction of the energy dissipated

A. Cyclones and wind speed

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 theoretical justification of this equation comes from the fact that the collision of a molecule with kinetic energy $\frac{1}{2}mv^2$ with an inelastic surface generates an energy loss of $\frac{1}{2}mv^2$ (supposing that the collision stops completely the molecule motion). 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 before $d\tau$ 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 an amount of time $d\tau$, in a given horizontal surface area ds is:

$$v\rho C_d d\tau ds = Pd\tau dS$$

B. Earthquakes and radiated energy

A note explaining why seismic moment is a good measure.

$$M_w = a \log(M_0) - b$$

$$M_0 = 10^{(M_w+b)/a}$$

Only a part of the seismic moment M_0 is effectively dissipated as radiated energy E_s , here we will ignore it:

$$E_s = M_0 = c10^{(M_w+b)/a}$$

Several studies propose the following attenuation pattern for a point P located at a distance d of the epicenter:

$$M(P) = M_w - \alpha d - \beta \frac{\ln(d)}{\ln(10)}$$

It is possible to construct the orthodormic distance 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:

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

B 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 2004 (C.Herold, F.Mouton, O.Norbeck, P.Peduzzi)

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

Table T1: Choice of parameters' values

Description	Parameter	Value	Units
<i>Earthquakes</i>			
Radiated energy - elasticity	a	6	-
Radiated energy - constant	b	2/3	-
Attenuation - linear term	α	.0005	kJ/m
Attenuation - logarithm term	β	.77	-
Radius	r	6371	km
<i>Cyclones</i>			
Surface drag coefficient	C_d	0.47	-
Air mass density	ρ	1.2	kg/m^3
<i>Density</i>			
Marginal returns to density	σ	1.13	-

- stands for dimensionless quantities. The earth radius is an average measure as the earth is nearly spherical.

Table T2: Most exposed countries

	Country	Frequency	Index	
			index 1	index 2
Earthquakes	1. Indonesia	61.1	60.5	43.8
	2. Afghanistan	5.3	59.3	45.4
	3. Russia	29.7	58.6	39.1
	4. Chile	16.4	57.4	46.2
	5. Bolivia	5.2	57.3	41.0
	6. Peru	9.5	57.2	41.8
	7. Ethiopia	.6	57.2	40.9
	8. Mexico	9.0	57.1	42.6
	9. Vanuatu	17.2	57.1	47.9
	10. China	9.3	57.0	39.1
Cyclones	1. Madagascar	2.2	17.6	4.65
	2. Japan	9.1	17.5	4.73
	3. Philippines	29.7	17.0	4.44
	4. United States	16.4	16.8	1.87
	5. Australia	5.2	16.5	<0
	6. China	9.48	16.4	1.46
	7. Mexico	.6	15.9	.93
	8. Mozambique	9.1	15.6	2.38
	9. Taiwan	17.2	15.4	-
	10. Russia	9.3	15.2	<0

Only cyclones and earthquakes between 1980 and 2006 are considered. The index 1 is the average energy dissipated on the territory of the considered country each year. Countries are ranked along this latter dimension. The second index corresponds to the same measure interpolated with density. Negative value for index 2 indicates extremely low value for the interpolation between density and energy dissipated. Here, Australia and Russia are often affected by cyclones in completely deserted regions.

Table T3: Comparing the objective indicators

First stage				
Declared damages				
	Earthquakes		Cyclones	
Magnitude (q)	.009 (.005) [†]	.011 (.005)*		
Energy-density index (q)		.032 (.005)**		
Wind speed (c)			-.007 (.100)	-.006 (.084)
Energy-density index (c)				.276 (.028)**
Propensity (q)	-.002 (.001)*	-.002 (.001) [†]		
Propensity (c)			-.002 (.006)	-.004 (.005)
Observations	1480	1480	238	238

Significantly different than zero at [†] 90% confidence, * 95% confidence, ** 99% confidence. Each observation is here an event, not a country/year. Observations are limited by the EM-DAT dataset and the availability of the magnitude/wind speed.

Table T4: Worst catastrophes sorted by the economic losses

Descriptive statistics						
Country/Year		Reports			Index	
country (region/name)		year	losses	affected	index 1	index 2
<i>absolute terms</i>						
Earthquakes	1. Japan (Kobe)	1995	84,712	542,000	55.05	44.07
	2. US (LA)	1994	33,240	27,000	55.01	42.64
	3. Italy (Napoli)	1980	32,147	400,000	57.63	44.01
	4. Japan (Niigata)	2004	29,696	62,183	54.64	41.86
	5. Turkey (Istanbul)	1999	20,103	1,358,953	44.76	31.34
Cyclones	1. US (Katrina)	2005	110,569	500,000	17.53	2.05
	2. US (Andrew)	1992	30,670	250,055	17.63	2.95
	3. US (Ivan)	2004	16,441	-	16.86	1.34
	4. US (Charley)	2004	14,614	30,000	16.73	1.88
	5. US (Rita)	2005	14,152	300,000	16.83	1.06
<i>relative terms</i>						
Earthquakes	1. Vanuatu	1982	10.2	-	48.74	38.82
	2. Ecuador (Carchi)	1987	.164	.015	55.25	41.37
	3. Nepal (Mahakali)	1980	.125	.016	56.24	43.26
	4. Algeria (El Asnam)	1980	.122	.049	57.71	45.73
	5. Salvador (Usulutin)	2001	.108	.223	57.51	47.12
Cyclones	1. Grenada (Ivan)	2004	1.89	.587	12.29	6.43
	2. St-Kitts & Nevis (Georges)	1998	1.39	.249	11.73	6.27
	3. St-Kitts & Nevis (Luis)	1995	.853	.043	11.80	6.26
	4. Antigua (Luis)	1995	.809	1 (!)	13.17	6.97
	5. Dominica (Marilyn)	1995	.781	-	11.46	4.80

Only cyclones and earthquakes between 1980 and 2006 are considered. Losses are indicated in constant 2000 \$ in absolute terms and as a ratio of GDP. Catastrophes are ranked along this dimension. The affected population is computed relatively to the total population in the second panel. The index 1 is the total energy dissipated on the territory of the considered country. The second index corresponds to the same measure interpolated with density.

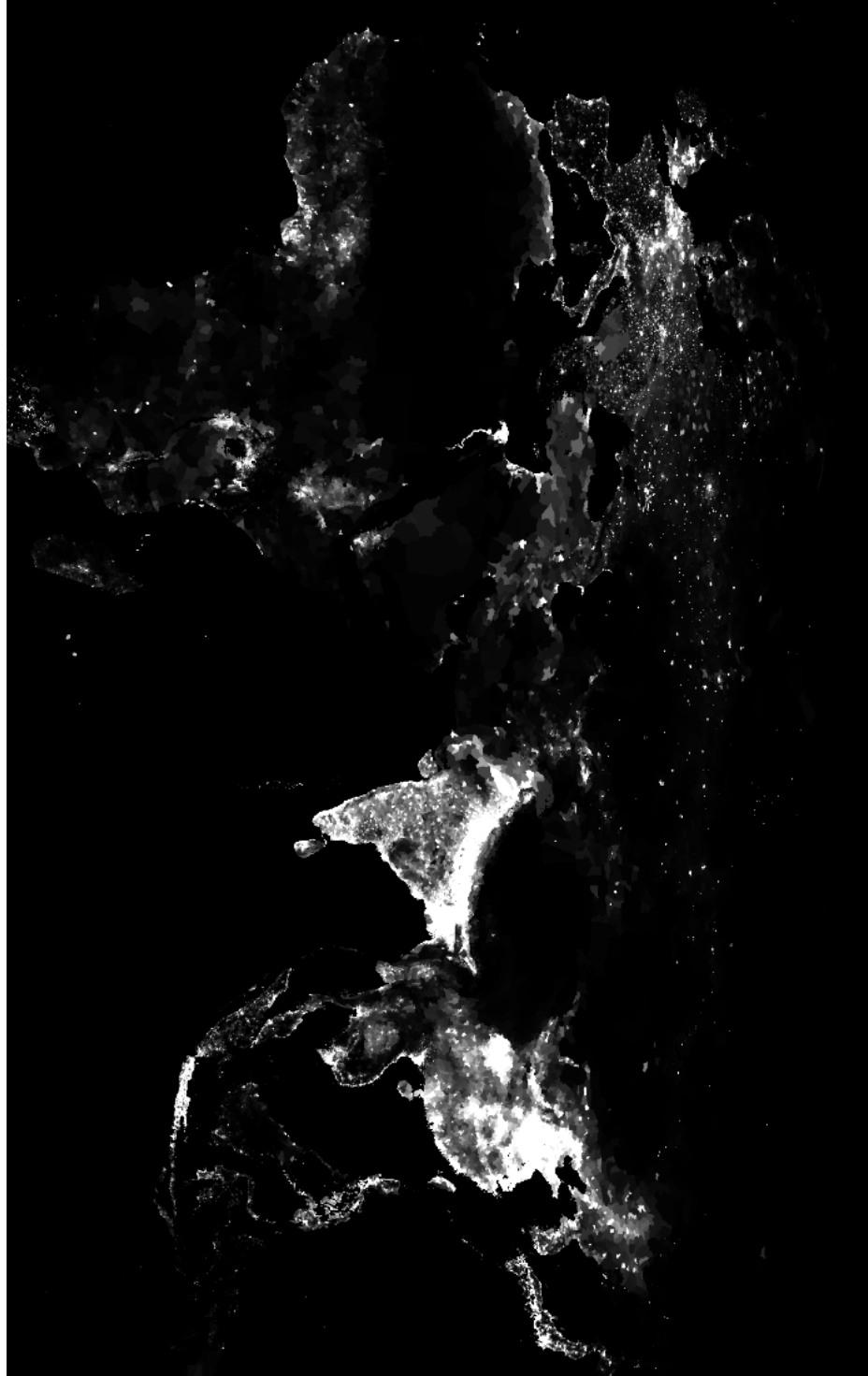


Figure F1: Density for Europe and Asia in 2000

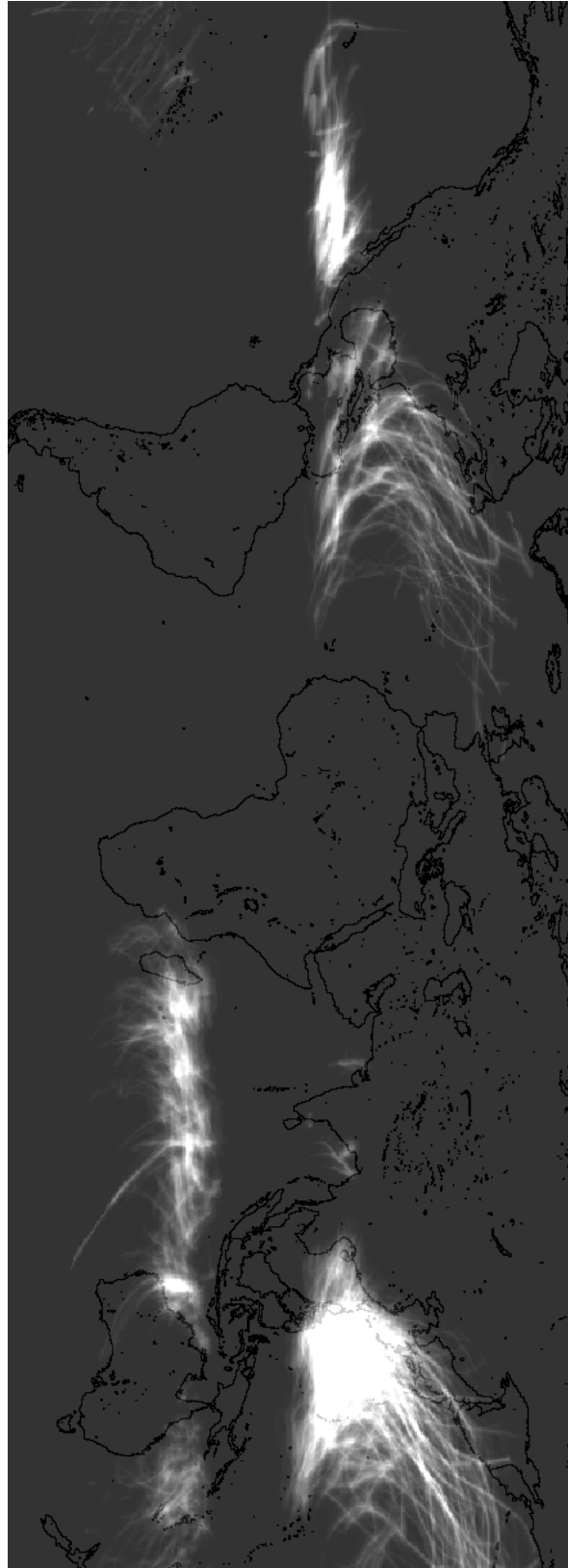


Figure F2: Tracks of cyclones since 1980

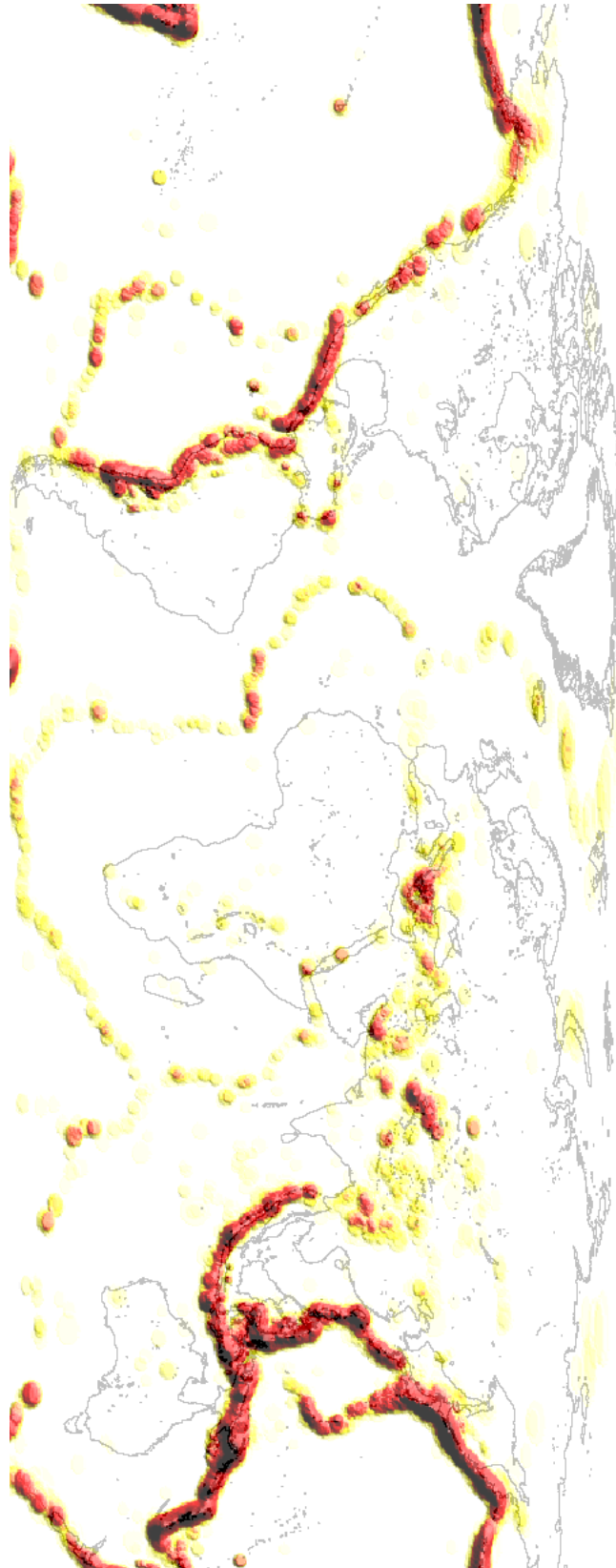


Figure F3: Frequency of tremors since 1965