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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 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 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 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. Finally, the objective measures happen to be better at predicting the economic slack than estimations from officials.

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I. Introduction

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]) have tried to estimate this impact and found a negative and significant effect of natural disasters on the immediate output. This paper complements these studies by providing a more systematic estimation of these effects.

Relying on a unique dataset of sudden disasters 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. Direct losses of $ 1 following cyclones or earthquakes 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 magnitude for the immediate production slack. Business disruption is the unobserved component which might explain the gap which exists 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, leaving economies close to the pre-disaster growth path. Consequently, this study depicts seemingly large but very non-persistent events. As I do not investigate the channels of propagation through the rest of the economy, this picture neglects differences of recovery across economies.

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.

The literature on macroeconomic consequences of natural disasters has roughly followed two leads. While Albala-Bertrand [1993], Noy [2009] and Strobl [2011] 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 channels of transmission[1]. 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] and Strobl [2011] 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], 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. 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. Even when the event is a quasi-experiment, reports of this event might alter the exogeneity of the initial experiment. This article alleviate this stumbling block by refining the choice of experiments - considered shocks will be sudden and characterized by objective indicators.

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

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[1] 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.

both have a large influence on the level of damages for 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.

Why do we need objective indicators? Losses are not completely verifiable. This feature is extremely important and explains the absence of formal private and public insurance. As such, entries might be biased downward (when not censored) 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. 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 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.

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. This article also puts forward a measure of the distribution of exposure in addition to raw measures of the overall exposure. 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.

In section II., I present the construction of the dataset and some descriptive statistics on exposure to natural disasters. Then, I discuss the empirical strategies and identifying hypotheses in section III.. Section IV. documents the estimations of income losses and proposes a simple interpretation of the magnitude of the effects. Extended results are discussed in section V., focusing on a potential catching-up effect few years later.

II. Construction of natural shocks

In this section, I provide a panorama of the data sources. I then detail the construction of local measures of exposure and how I aggregate them to match macroeconomic data. Finally, I give some descriptive statistics on exposure.

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 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 part of them having landed though). Wind intensity, pressure, precise location, form and size of the eye are precisely documented every 6 hours. 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 world[2].

The earthquakes studied here are extracted from Earthquake 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

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[2] the 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 - a square of 30 kms around the equator.

given about the identity of the fault, the magnitude and type of measure, the date, the position of the epicenter and the depth. Using this information, it is possible to reconstitute the sum of all hazard realizations (approximately 20000 tremors with a magnitude above 5) providing a good idea of potentially affected regions. Similarly than for cyclones, Global Earthquake Hazard Frequency and Distribution data complements the data on tremors by giving fixed characteristics of faults and the exposure profile for a grid of 0.25 degree of latitude and 0.25 degree of longitude.

To complement these objective indicators, I use a catalog of natural disasters. EM-DAT[3] 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[4] 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... 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 data are often truncated to zero when it comes to economic or human damages.

The data about population densities is extracted from the Gridded Population of the World[5]. 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. Figure F1 gives a

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

[4] 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.

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

good idea of the level of disaggregation picturing Asia and Europe in 2000.

As for the macroeconomic indicators, they are extracted from World Development Indicators, Penn World table and Global Development Finance.

B. Data construction

This part will focus essentially on the construction of local objective indicators for a particular area affected by a catastrophe. I will then discuss the aggregation of this local measure to derive the catastrophe exposure and the annual exposure.

A measure of energy

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 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.

For cyclones, Bister & Emanuel [1998] and Emanuel [2005] propose a measure proportional to the cube of wind speed.

$$E_c \propto v^3 \tag{1}$$

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.

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. 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. For an area exposed to M_w,

$$E_q \propto 10^{(M_w+b)/a} \tag{Es}$$

This measure is the energy dissipated at the focal point as M_w is given by geological institutes at the epicenter of the tremor. It is possible to derive such a measure for areas close to the epicenter. In the appendix, I detail the exact corrections for distance attenuation. The construction rely on estimates provided by Choy & Boatwright [1995]. Considering that these constant are uniform over the globe is certainly leading us to measurement error. As before, the estimations implicitly ignores regional differences. Notwithstanding, there are no evident biases induced by these approximations.

Finally, note that I implicitly neglect the fact that different zones may differ in their resistance to a similar level of energy. I consider energy as the relevant indicator of natural threat.

A measure of exposure

Pure dissipation of energy is a poor indicator of direct damages. These estimates need at least to be weighted by the quantity of assets at stake. The only local available information on economic activity at such a disaggregated level is the density of population. The simplest way to compute a measure of exposure is to interact the energy with the quantity of assets at stake in a local area τ - approached by the density $d_e(\tau)$. Four measures of exposure might then be related to direct damages for a given event:

- maximum wind speed, magnitude at the epicenter (rough natural exposure)
- the total energy dissipated along the earthquake or the typhoon (refined natural exposure), $E_q(\tau)$ for a particular area τ and $\int E(\tau)d\tau$ along the whole catastrophe.

These two measures ignore the economic activity at stake and focus on the pure natural threat.

- the total energy dissipated along the earthquake or the typhoon weighted by the local density of population (weighted sum of natural exposure), $E(\tau)d_e(\tau)$ for a particular area τ and $\int E(\tau)d_e(\tau)d\tau$ along the whole catastrophe.

- proportion of the population exposed to at least a certain threshold of energy E (cumulative natural exposure), $\mathbb{1}_{E(\tau)\geq E}d_e(\tau)$ for a particular area τ and $\int \mathbb{1}_{E(\tau)\geq E}d_e(\tau)d\tau$ along the whole catastrophe. Regarding cyclones, the thresholds will be defined along rough equivalents of the categories given to tropical typhoons by NOAA (from tropical storm, which will be assigned to cat. 0 to cat. 5 typhoons which will be assigned to cat. 5). Similarly, for earthquakes, the thresholds of energy will be computed such as to match the energy at the epicenter of a magnitude 5.5 (cat. 0), 6 (cat. 1), 6.5 (cat. 2), 7 (cat. 3), 7.5 (cat. 4), 8 (cat. 5) earthquake.

These last two measures will be preferred as they account for the assets at risk.

Before turning to the aggregation issue, let me discuss the choice of density of population as the indicator of capital density. Note that wealth and capital could be more concentrated than population. Capital density exhibits increasing returns to population density. With OECD data on sub-national divisions of population and capital, an additional 1% in population density for a region within a country is associated with an additional 1.13% in capital density for this region. I will ignore this correction as it does not provide significant improvement on the predictive power of the index developed here.

Once constructed the index at the catastrophe level, I aggregate over the year for a particular country the last three index. This process creates country/year observations for the last three measures, (i) total energy dissipated, (ii) total energy dissipated corrected by density, (iii) proportions of the population exposed to 6 thresholds corresponding to scientific standards. These measures will be constructed for earthquakes and cyclones separately but most of the study will consider those two exposures together and treat the energy dissipated by the two events as directly comparable. In practice, I will weight each catastrophe by the number of months for which each catastrophe may have contributed to the output loss i.e. the number of months between the catastrophe and the end of the year. For a given country, cyclones often occur in a small window of two to three months. As such, controlling for window of exposure is not as crucial as for earthquakes. For both, I weight each catastrophe by the number of months for which they could have affected ongoing production. Remark that I do not attribute the residual of this operation to the following year.

A measure of average exposure

Natural disasters are unpredictable in the sense that an occurrence can never been 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. 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 most frequent disasters occurs in places where unobserved mitigation is the weakest.

I use first a project Global 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. I create measures of the expected loss for each country/year using the propensity to be hit coupled with the evolution of the economic activity.

C. Descriptive statistics

Figure F2 and F3 show 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 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 T3 shows few countries among the most highly exposed ones to natural threat. 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. For these economies, I present the aggregate exposure over the period 1980-2006 as described by subjective and objective indicators. Interestingly, the total proportion of people declared as affected by a catastrophe during this period is close to the objective proportion of individuals computed for the lowest threshold. Regarding earthquakes over this period 1980-2006, Chile and Salvador lost the equivalent of one year of production and the aggregated number of people affected passes above twice the population of those countries. Japan has lost 5 months of production for very similar objective exposure. Losses are smaller for hurricanes. The United States has lost 2 weeks of production over the whole period - essentially driven by Andrew and Katrina.

Based on economic and human losses reported in EM-DAT, table T4 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 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 tropical cyclone Galifo in Madagascar were larger shocks from this perspective.

With such shocks, many channels of propagation can be considered. Ecuador (earthquake, 1987), Grenada (hurricane Ivan, 2004) and Saint-Kitts and Nevis (hurricane Luis, 1998) among others 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 1987 earthquake in Ecuador unquestionably froze some economic sectors of Ecuadorian production. The Trans-Ecuadorian pipeline 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 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 details, this agricultural economy suffered from important crop losses and the water system underwent severe damages. As for 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 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 evolution of output with a large disruption quite absorbed after one year, once smoothed the distortions induced by the catastrophes. On the opposite, immediate losses in t are small in the case of Saint-Kitts and Nevis but there seems to be a more persistent component which slows production in the long run.

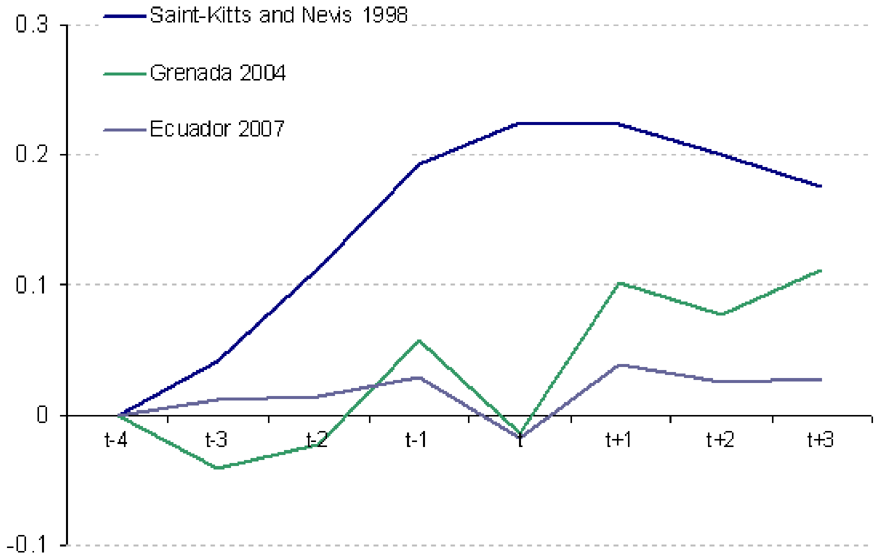

Figure 1: Some examples of economic disruption (the ordinate is a normalized GDP defined as the output increase in constant terms relatively to GDP at $t-4$.

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, insured damages have offset respectively 40% and 15% of losses due to typhoons in Japan and earthquakes in United States since 2000. Furthermore, insurance concerns mainly capital losses and does not mitigate losses from business disruption. 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 events[6]. Accordingly, countries in the wake of a shock first and foremost rely on reserves, debt relief or suspension of external debt payment and austerity plans.

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

III. Empirical strategies

To assess the amplitude of the economic slowdown following a year t for a country i exposed to D_t^i , I assume a linear relationship between the level of annual direct damages normalized by GDP, $d_t^i = D_t^i/Y_t^i$, and the indirect downturn in domestic production measured by the output growth during the period t, $y_t^i = (Y_t^i - Y_{t-1}^i)/Y_{t-1}^i$.

$$y_t^i = \beta_d \left(d_t^i - E\left[d_t^i\right]\right) + E\left[y_t^i | d_t^i = E\left[d_t^i\right]\right]$$

Let us examine now how the counterfactual $\tilde{y}_t^i = E\left[y_t^i | d_t^i = E\left[d_t^i\right]\right]$ can be accounted for. In a first instance, a broad set of controls X_t in t might prove sufficient to capture this counterfactual. Gross capital formation, current account, exports, government consumption and reserves are chosen to clean the output growth from external shocks and government responses. Nonetheless, catastrophe may affect simultaneously with output the control variables X_t. The results presented here are unchanged when considering these controls at date $t-1$.

$$\tilde{y}_t^i = \beta_y y_{t-1} + \beta_x X_{t-1} + \varepsilon_t^i$$

Two types of measures can capture the level of annual direct damages, (i) declarations of damages reported in EM-DAT, (ii) objective measures of exposure, both summed over the year. Expected losses are captured by the index p_t^i constructed as the interaction of the evolution of the density of population and the raw propensity to be hit. The following model is tested with d_t^i captured by reported losses dd_t^i or objective measures de_t^i,

$$y_t^i = \beta_d d_t^i + \beta_p p_t^i + \beta_y y_{t-1} + \beta_x X_t + \nu_i + \gamma_t + \varepsilon_t^i \qquad (2)$$

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 objective proxies for the exposure are not correlated to unpredicted growth of domestic production except through the measure of direct losses, the following model is identified.

$$\left\{ \begin{array}{ll} dd_t^i = \alpha_e de_t^i + \alpha_p p_t^i + \alpha_y y_{t-1} + \alpha_x X_t + \rho_i + \delta_t + \mu_t^i & (s_1) \\ y_t^i = \beta_d \hat{dd}_t^i + \beta_p p_t^i + \beta_y y_{t-1} + \beta_x X_t + \nu_i + \gamma_t + \varepsilon_t^i & (s_2) \end{array} \right. \tag{3}$$

The identification method relies on a two step process. First, declared losses are predicted by the energy-density index. The second step is the estimation of the transmission of direct damages into indirect economic losses. As energy-density index are computed using past density of population 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 two specifications is that they impose a constant transmission parameter β_d across country, leaving aside the possibility that economies might differ in their ability to recover from severe capital shocks.

IV. Amplitude of economic disruption

In this section, I will first estimate the amplitude of the economic slack following a shock. I will then propose simple assumptions and try to decompose this average effects into a direct effect due to capital losses and a residual ("business disruption").

Table 1: Hypothetical first stage - a link between declared damages and objective measures

First stage

	Declared damages (% of GDP)					
Energy index	sum	threshold				
		cat. 0	cat. 1	cat. 2	cat. 3	cat. 4
				Cyclones only		
Energy index (q)	-.015	-.124	-.247	-.232	-.332	-.422
	(.187)	(.206)	(.396)	(.476)	(.890)	(1.31)
Energy index (c)	.350	.203	.204	.822	1.73	6.59
	(.038)**	(.075)**	(.076)**	(.151)**	(.225)**	(.486)**
Propensity (q)	.003	-.002	-.003	-.004	-.004	-.004
	(.021)	(.021)	(.021)	(.021))	(.021)	(.021)
Propensity (c)	.069	.107	.107	.094	.096	.081
	(.032)*	(.032)**	(.033)**	(.032)**	(.032)**	(.031)**
Observations	4629	4629	4629	4629	4629	4629
				Earthquakes only		
Energy index (q)	.822	.231	.688	.739	1.49	2.21
	(.035)**	(.040)**	(.077)**	(.093)**	(.173)**	(.259)**
Energy index (c)	-.001	-.002	-.003	-.001	-.002	-.006
	(.007)	(.015)	(.015)	(.029)	(.044)	(.096)
Propensity (q)	.003	.003	.004	.004	.003	.003
	(.004)	(.004)	(.004)	(.004)	(.004)	(.004)
Propensity (c)	-.003	-.005	-.007	-.006	-.005	-.005
	(.006)	(.006)	(.006)	(.006)	(.006)	(.006)
Observations	4624	4624	4624	4624	4624	4624

Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. The observations are here country/year. Variables are thus the sum over the year of index for each catastrophe corrected by the month of occurrence. Category 0,1,2,3,4 corresponds to cyclones classification and to moment magnitude of 5.5,6,6.5,7,7.5 at the epicenter for earthquakes.

Estimates

Before analyzing the effect of direct losses on domestic production, let us establish the power of physical measures at predicting declared losses. Two different specification capture the link between objective estimates and declarations of losses. The first specification establishes this relationship for each catastrophe. The second one hinges on country/year aggregates and constitute the first stage (s_1) of the two stage strategy presented in the previous section. Table T5 in the appendix highlights that objective estimates are very good predictors of declared damages using catastrophe observations. One standard deviation of the corrected sum of energy generates damages of the order of 2.75 points of GDP for earthquakes and 1.8 for cyclones. This table also shows that the decomposition of this index into layers of exposure[7] has a very good predictive power. The more violent an event affect a fixed part of the population the more likely it is to transfer into damages. Table 1 confirms this pattern. The observations are then country/year and I compare aggregate declared damages to aggregated index for a country over the year. Declared damages due to cyclones (resp. earthquakes) are only affected by the cyclone (resp. earthquakes) measure of energy dissipated. 1% of the population affected by a category 0 cyclone generates losses of the order of .2 GDP points. This estimate increases to .8, 1.7 and 6.6 points of GDP for categories 2,3 and 4 cyclones. Regarding earthquakes and with 1% of the population affected, the elasticity goes steadily from .23 GDP points (cat. 0) to .69 (cat. 1), .74 (cat. 2), 1.5 (cat. 3), and 2.2 (cat. 4). These figures are naturally increasing with the considered thresholds confirming the decomposition into layers shown in T5.

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. First, the results are substantially lower than without propensity measures[8]. 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. The indirect losses

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[7] each layer represents the number of people affected by an amount of energy between two categories.

[8] 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%.

Table 2: Influence of direct losses on domestic production

Second stage

	output growth (t)							
Specifications	**(S1)**		**(S2)**		**(S2)**		**(S2)**	
Instruments			**sum**		**thresh.** 0		**thresh.** 2	
Declared losses	-.052	-.066	-.422	-.369	-.427	-.330	-.455	-.403
	(.036)	(.035)†	(.182)*	(.180)*	(.197)*	(.187)†	(.187)*	(.180)*
GDP growth	.292	.186	.292	.186	.292	.186	.292	.186
(t-1)	(.015)**	(.016)**	(.016)**	(.016)**	(.016)**	(.016)**	(.016)**	(.016)**
Year f.e.		Yes		Yes		Yes		Yes
Country f.e.		Yes		Yes		Yes		Yes
Observations	3487	3487	3487	3487	3487	3487	3487	3487

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 from earthquakes or wind-based events divided by current GDP. The set of controls groups gross capital formation, government consumption, total reserves and current account. The endogeneous variable is the variable *declared losses*. The instruments are the sum of the energy index weighted by the density of population and the proportion of the population affected by a cat. 0 event, cat. 2 event. The results are robust to the addition of domestic credit, imports, FDI inflows and GDP per capita as controls. The simplest specifications are displayed here.

climb up to roughly 40% of the initial capital losses. Incidentally, these results are statistically significant and robust to the addition of fixed effects, other controls and even to the choice of instruments (corrected sum of exposure, thresholds...). In fact, they are even robust decomposing between earthquakes and cyclones (see table T2 in the appendix). Note 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 capacities[9]. 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.

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

Specification (S1)

	output growth (t)					
Threshold	cat. 0		cat. 2		cat. 3	
Declared losses	-.038	-.055	-.037	-.054	-.038	-.055
	(.037)	(.036)	(.037)	(.036)	(.037)	.036
Index	-.468	-.469	-.771	-.691	-.962	-.829
	(.232)*	(.283)†	(.361)*	(.380)†	(.477)*	(.477)†
GDP growth	.292	.186	.292	.186	.292	.186
(t-1)	(.015)**	(.016)**	(.015)**	(.016)**	(.016)**	(.016)**
Year f.e.		Yes		Yes		Yes
Country f.e.		Yes		Yes		Yes
Observations	3487	3487	3487	3487	3487	3487

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 from earthquakes or wind-based events divided by current GDP. The index are the proportions of the population affected by a cat. 0 (resp. 2,3) event. The set of controls groups gross capital formation, government consumption, total reserves and current account. The results are robust to the addition of domestic credit, imports, FDI inflows and GDP per capita as controls. The simplest specifications are displayed here.

Not only physical exposure is a good instrument, but also simply a good predictor of indirect losses independently of declarations. As made explicit in table 3, adding the physical annual exposure offset the predictive power of declared losses. Comparatively, a production slack of .47 (resp. .77 and .9) points of GDP echoes an additional 1% of the population affected at least by a category 0 (resp. 2 and 3) event. Even though the framework here is not completely fit for applying the Wald

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

estimator, the coefficient found during the regressions above are consistent with the Wald approach.

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 define a framework and a privileged channel of production slowdown - capital losses. Consider in this regard that direct damages reported in EM-DAT are losses of productive capital. In practice, those losses encompass the destruction of unproductive units of capital and supposedly[10] a potential freeze of the economy. 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, $\frac{dK}{K} = d_d\frac{Y}{K}$. 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 at most .4. Consequently, the elasticity of output loss should be lower than .05 (which represents also an upper bound for the interest rate as $\alpha(Y/K) = r$) under the previous assumptions. The predicted value of $\frac{y}{d_d}$ is far lower than the coefficient .4 found in the empirical specifications.

Keeping the assumption that $\frac{dA}{A} = 0$, 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

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[10] this claim might be true but for very few catastrophes.

high. A decrease of capital is then followed by the same decrease in labor $\frac{dK}{K} = \frac{dL}{L}$. 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 Shimer [2010]). 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 $\frac{dA}{A}$ accounts at least for two third of the estimated losses. This feature tends to indicate that most of the immediate losses are due to business disruption affecting productivity, labor supply... This feature 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.

V. Catching-up with the growth path?

The previous section has highlighted the presence of an economic slack created by natural disasters. 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 the catastrophe, which might be due to non-restored capital stocks - after the severe damages incurred to the irrigation system 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.

As reported in table 4, the immediate effect of cyclones on economic production is temporary. An additional 1% of the population affected at least by a category 2 event induces an immediate economic slack of .8 points of GDP growth, offset one year later. Still, there are no evidence of a mean reversion. As such, the excess growth one year after the shock allows the economy to catch up with the pre-shock

Table 4: Catching up with the growth path

Specification (S1)

		output growth (t)					
Specifications		OLS	OLS	OLS fe	OLS	OLS	OLS fe
Energy-density index	t	-.759	-.706	-.876	-.821	-.774	-.852
		(.384)*	(.383)†	(.378)*	(.386)*	(.385)*	(.376)*
	$t-1$	-.244	-.146	-.421	-.251	-.154	-.272
		(.375)	(.374)	(.386)	(.385)	(.383)	(.385)
	$t-2$	-.570	-.485	-.722	-.580	-.482	-.585
		(.375)	(.374)	(.386)†	(.384)	(.382)	(.388)
	$t-3$	-.442	-.376	-.429	-.444	-.378	-.345
		(.381)	(.383)	(.377)	(.397)	(.395)	(.391)
	$t-4$				-.112	-.072	-.0176
					(.385)	(.384)	(.390)
	$t-5$				-.004	-.002	.012
					(.434)	(.433)	(.420)
	$t-6$				.033	.042	.045
					(.420)	(.419)	(.398)
GDP growth	$t-4$	.012	.016	-.039			
		(.015)	(.015)	(.015)*			
GDP growth	$t-7$				.000	.006	-.014
					(.014)	(.014)	(.014)
Year f.e.				Yes			Yes
Country f.e.				Yes			Yes
Controls		C_1	C_2	C_2	C_1	C_2	C_2
Observations		3112	3058	3058	2700	2662	880

Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. The dependent variable is the GDP growth for the ongoing year. The set of controls C_1 groups gross capital formation, government consumption, total reserves and current account. C_2 adds domestic credit, imports, FDI inflows and GDP per capita to C_1. The index is the proportion of the population affected by a cat. 2 event. The simplest specifications are displayed here.

level of 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.

In order to confirm these intuitions, I define a catch-up indicator equal to 1 once the real pre-disaster growth path has been caught up. This defines also a the number

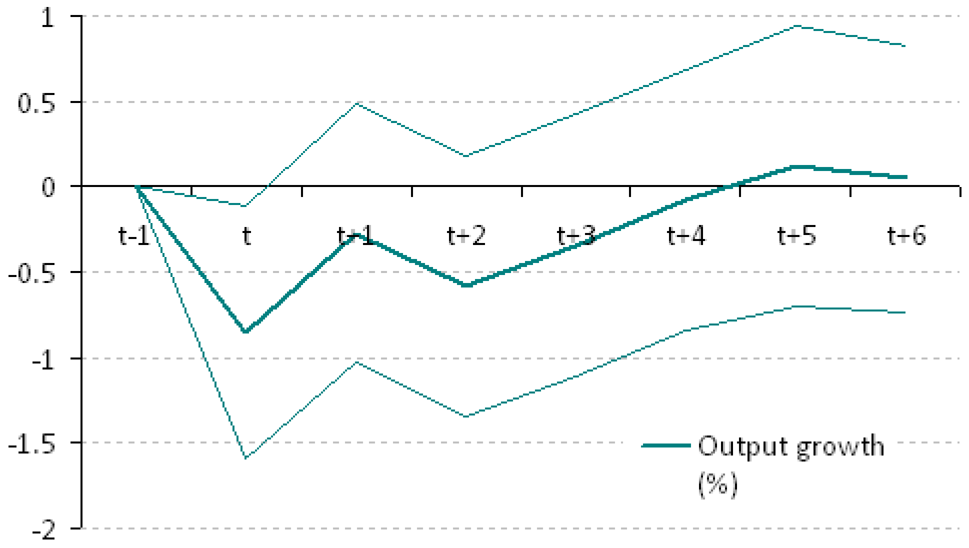

Figure 2: Evolution of GDP and GDP growth rate following a catastrophe (GDP normalized to 1 in $t-2$)

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. 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 test additional specifications and show that the results are not 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 simple output-growth 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 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

Table 5: Catching up with the growth path - duration analysis

Specification (S1)								
	years before recovery							
	partial recovery				**full recovery**			
Specification	Poisson		Neg. bin.		Poisson		Neg. bin.	
Index	49.3 (8.61)**	79.3 (15.1)**	43.1 (23.2)†	84.25 (29.9)**	28.9 (17.0)**	47.6 (.477)†	23.5 (26.7)	54.7 (31.5)†
GDP growth (t-1)	-2.28 (.665)**	-.407 (.773)	-2.79 (1.23)*	-.603 (1.35)	-1.73 (.621)**	-.483 (.742)	-2.03 (1.10)	-.392 (1.23)
Year f.e.		Yes		Yes		Yes		Yes
Country f.e.		Yes		Yes		Yes		Yes
Observations	2470	2470	2470	2470	2356	2356	2356	2356

Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. The dependent variable is the number of years needed for growth to catch up with the pre-growth path (computed using $t-1$, $t-2$, $t-3$) bounded upwards to 4 years. Full recovery means that growth pass above the average counterfactual growth, partial recovery means that growth is .5 points of growth close to the average counterfactual path. The set of controls groups gross capital formation, government consumption, total reserves and current account. The index is the proportion of the population affected by a cat. 2 event. The results are robust to the addition of domestic credit, imports, FDI inflows and GDP per capita as controls. The simplest specifications are displayed here.

additional 1% of the population affected at least by a category 2 event increases recovery time by approximately 6 to 9 months. This result is not entirely due to immediate recovery as accounting for the over-representation of immediate exit with the negative binomial specification does not change the qualitative insights.

VI. Concluding remarks

This paper has documented how large natural disasters might provoke a slowdown of production. The amplitude of the recession is particularly large. 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 and earthquakes 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.

Finally, a side result of this study concerns biases and censorship issues for reports from officials. They seem to be astonishingly large. In particular, 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”).

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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 2004 (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 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 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 stops completely 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 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 time $d\tau$ for a given horizontal surface area dS is the product of those three quantities:

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

Assuming ρ and C_d constant around the globe,

$$P \propto v^3 d\tau dS$$

B. Earthquakes and 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. Here, I will ignore the other channels through which tremors dissipate energy.

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

where M_w is the moment magnitude supplied by most of the geological institutes. An issue is that this measure is given at the epicenter only. Choy & Boatwright [1995] proposes the following attenuation pattern for a point P located at a distance d of the epicenter:

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

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:

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

Accordingly, the local energy dissipated at a distance d can be written as $E_q = M_0 = c10^{(M_w - \alpha d - \beta \frac{\ln(d)}{\ln(10)} + b)/a}$ with d derived from the latitude and longitude as shown above.

Table T1: Choice of parameters' values

Description	Parameter	Value	Units
Earthquakes			
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
Cyclones			
Surface drag coefficient	C_d	0.47	-
Air mass density	ρ	1.2	kg/m^3

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

C Tables and figures

Table T2: Influence of natural disasters on domestic production - earthquakes against cyclones

	Specification (S2)			
	output growth (t)			
Instruments	**Cyclones**		**Earthquakes**	
Declared losses	-.421 (.179)*	-.341 (.171)*	-.738 (.475)	-1.17 (.691)†
GDP growth (t-1)	.292 (.016)**	.186 (.016)**	.293 (.016)**	.185 (.018)**
Year fixed effects		Yes		Yes
Country fixed effects		Yes		Yes
Controls	C_1		C_1	
Observations	3487	3487	3487	3487

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 from earthquakes or wind-based events divided by current GDP. The set of controls groups gross capital formation, government consumption, total reserves and current account. The instruments are for the earthquake (resp. cyclone) specification the sum of the energy index weighted by the density of population and the proportion of the population affected by a cat. 0 and cat. 2 earthquake (resp. cyclone) together. The results are robust to the addition of domestic credit, imports, FDI inflows and GDP per capita as controls. The simplest specifications are displayed here.

Table T3: Examples of highly exposed countries between 1980-2006, reports and objective indicators

		Reports		**Objective measures**		
	Country	Losses	Affected	Thresholds		
				0	1	2
Earthquakes	Chile	.977	2.34	.199	.032	.016
	Salvador	1.03	2.02	.230	.035	.019
	Indonesia	.326	.343	.077	.017	.012
	Philippines	.066	.268	.171	.021	.011
	Japan	.361	.128	.205	.033	.020
Cyclones	Philippines	.079	.895	.255	.055	.009
	Vietnam	.078	.624	.044	.043	.004
	Madagascar	.233	.318	.256	.080	.017
	China	.035	.149	.024	.023	.002
	United States	.029	.038	.016	.015	.004

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 energy above the equivalent of a cat. n event. All these index are summed over the period 1980-2006.

Table T4: Example of catastrophes, reports and objective indicators of exposure

	Country/Year		**Reports**		**Obj. measures**		
	Country	Year	Losses	Affected	Thresholds		
					0	1	2
Earthquakes	Pakistan	2005	.055	.033	.011	.001	.000
	Japan (Kobe)	1995	.022	.004	.004	.002	.002
	Salvador	2001	.112	.223	.031	.005	.004
	Chile (Santiago)	1985	.051	.122	.049	.014	.010
Cyclones	US (Katrina)	2005	.010	.002	.001	.001	.000
	US (Andrew)	1992	.008	.006	.043	.042	.037
	Madagascar (Galifo)	2004	.057	.058	.017	.017	.004
	Guam (Chata'an)	2002	-	.025	.021	.020	.014

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 energy above the equivalent of a cat. n event.

Table T5: Direct damages predicted by objective indicators

First stage

		Declared damages			
		Earthquakes		Cyclones	
Magnitude (q)		.0026 (.0004)**			
Energy-density index (q)		.0275 (.0049)**			
Energy-density index (q)	[0,1)		10.36 (.7776)**		
Energy-density index (q)	[1,2)		3.415 (1.676)*		
Energy-density index (q)	[2,3)		17.91 (1.701)**		
Energy-density index (q)	[3,4)		33.24 (3.814)**		
Energy-density index (q)	[4,5)		49.18 (6.942)**		
Energy-density index (q)	above 5		132.7 (11.92)**		
Maximum wind speed (c)				.00014 (.00007)†	
Energy-density index (c)				.0179 (.0056)**	
Energy-density index (c)	[1,2)				.2141 (1.124)
Energy-density index (c)	[2,3)				4.670 (1.144)**
Energy-density index (c)	[3,4)				1.966 (1.912)
Energy-density index (c)	[4,5)				13.19 (3.654)**
Energy-density index (c)	above 5				14.74 (6.671)*
Adjusted R-squared	0.7987	0.6873	.3649	.4481	
Country fixed effects	Yes	Yes	Yes	Yes	
Observations	1469	1594	282	567	

Significantly different than zero at † 90% confidence, * 95% confidence, ** 99% confidence. Declared losses are losses from earthquakes or wind-based events divided by current GDP. Each observation is here an event, not a country/year. The energy density index is the sum of the energy dissipated locally weighted by the population exposed. The interval $[0, 1)$ is the proportion of the population exposed to energy between cat. 0 and cat. 1. The number of observations is limited by the magnitude and wind speed provided by EM-DAT. The variable threshold [0,1) has been dropped for cyclones due to the very few observations with low energy.

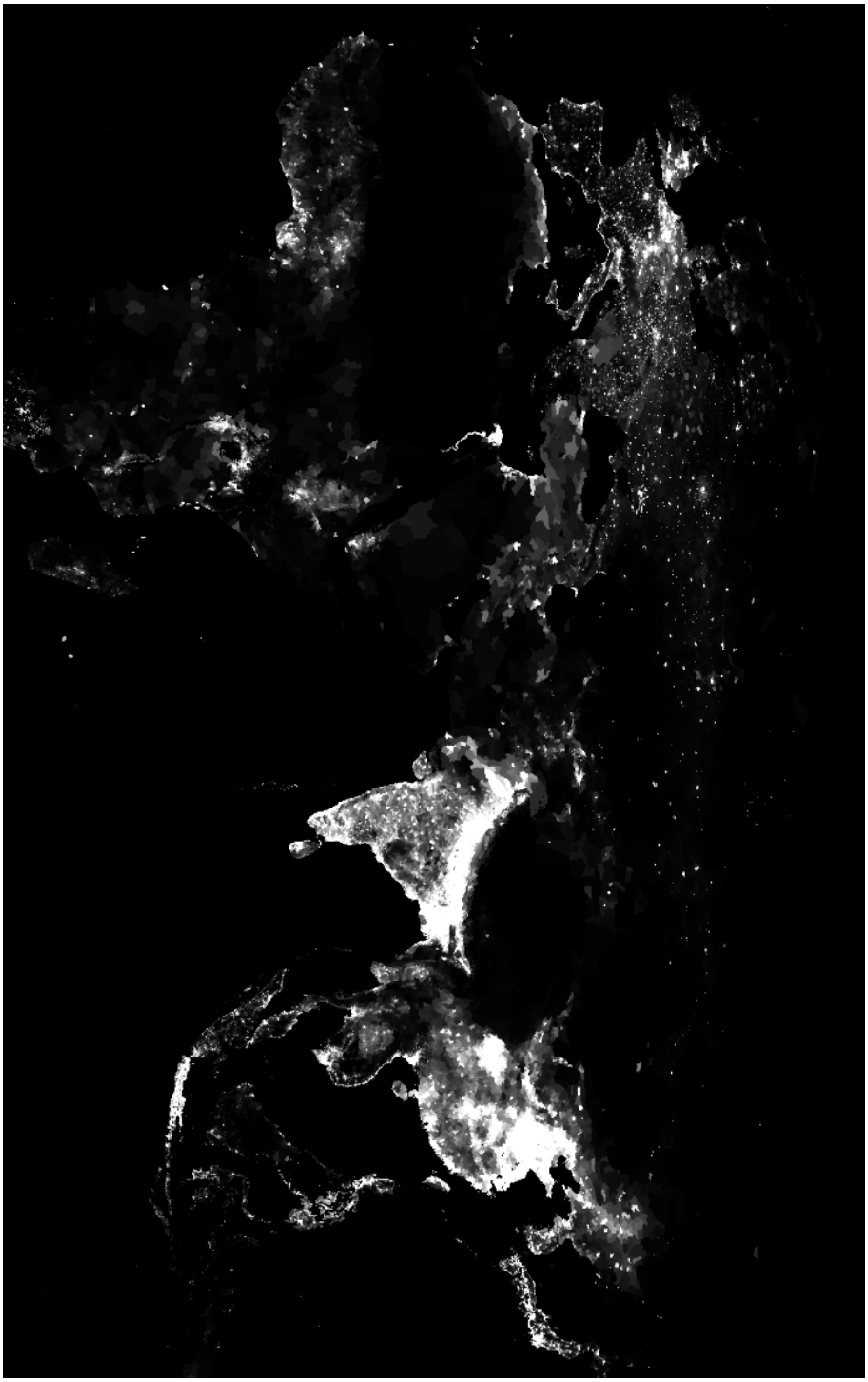

Figure F1: Density for Europe and Asia in 2000

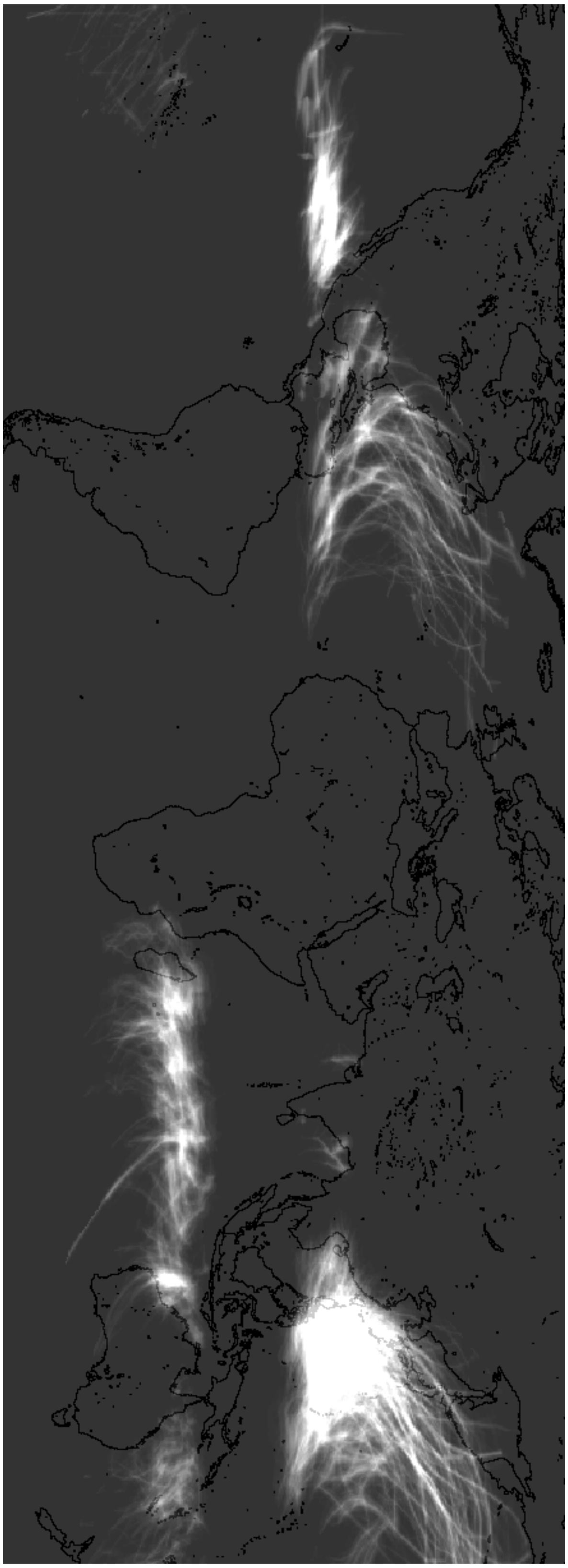

Figure F2: Tracks of cyclones since 1980

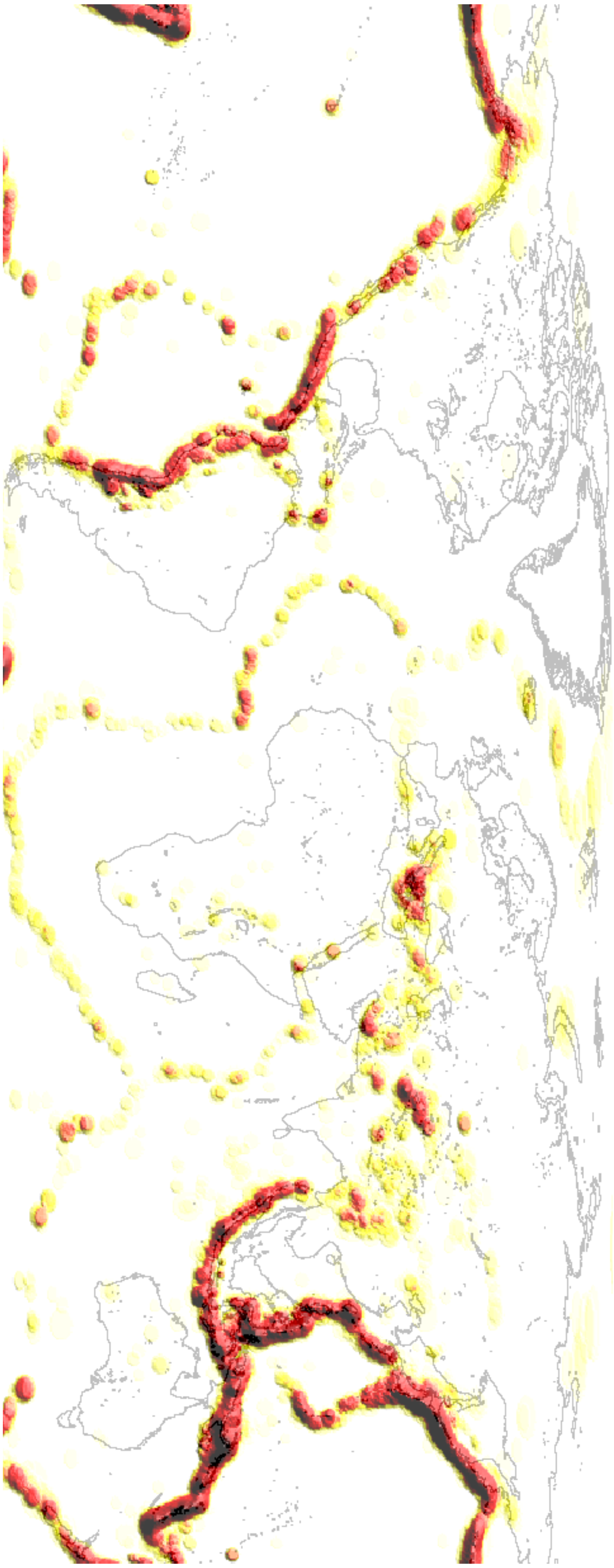

Figure F3: Frequency of tremors since 1965