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JEL Codes: E22, O16, Q54

Keywords: Natural disasters, credit constraints, resources misallocation



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Capital misallocation and credit constraints: Theory and evidence from natural disasters

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July 7, 2011

Abstract

This article builds a model of financial frictions to explain the aftermath of natural disasters. In constrained economies, after a large shock on capital, affected entrepreneurs might lose access to credit together with their stock of capital. Investment does not flow to high-returns projects. Accordingly, in constrained economies, a shock on capital is associated with an initial decrease of domestic credit and an investment slack. I find direct support for the theoretical model using objective measures on sudden natural disasters between 1980 and 2006. Constrained economies experience an initial decline in their level of investment, which reflects on the immediate GDP growth. This effect fades away after 3 years. In frictionless environment, the increase of credit offsets almost perfectly the estimated capital losses. The underlying credit frictions computed using a structural equation prove to be correlated to more classic measures of financial development.

Keywords: Natural disasters, credit constraints, resources misallocation.

JEL classification: E22, O16, Q54

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I. Introduction

In credit-rationed environments, misallocations of resources across production units might persist. This feature has already been established by a literature using firm-level dataset¹. Large natural calamities destroy physical capital and, in financially underdeveloped environments, the induced distortion may not be immediately absorbed by credit markets.

A natural disaster should be followed by a credit expansion in order to restore the pre-catastrophe level of capital. There is a risk of double penalty in the wake of a large natural calamity: in addition to capital losses, entrepreneurs may lose collateral up to the point where access to credit become restricted. The investment of those highly productive units will be temporarily lower than their ideal level. This paper builds upon the observation that the recovery period following a natural disaster can be long even for apparently fast-growing countries and relates this inertia to the presence of credit constraints.

I model a simple dynamic economy of infinite-horizon agents with heterogeneous endowments and financial frictions. From this stylized framework, I derive the deterministic evolution of the distribution of capital, consumption, credit and interest rate in a closed form system of equations. The intuition behind the model is fairly straightforward: in the wake of a shock, some entrepreneurs will be denied access to credit and thus maintain an activity far below its ideal level. I test the predictions of the model on a unique dataset of cyclones and earthquakes between 1980 and 2006. The dataset relies on wind trails and tremors weighted by the local density of population and provides precise and objective measures of the distribution of capital losses for each event.

Matching these occurrences with macroeconomic indicators on a large panel of countries, I find direct support for the theoretical predictions. Credit constraints account for a large part of the inertia following cyclones and earthquakes. Countries exhibiting larger credit market frictions catch up at a slower pace with the

¹see McKenzie for an analysis on small businesses following the 2004 tsunami and Manova [2008] for indirect evidence in Guatemala.

initial growth path. This result is the consequence of a credit squeeze of significant magnitude in constrained economies. At the other end of the spectrum, frictionless economies experience an increase of the loans provided to the private sector which offsets the estimated capital losses. The differential response to the shock between countries is largely explained by this dimension. The estimation of a structural equation derived by the theory is compatible with a model of credit rationing with higher inertia for countries with an under-developed financial sector. The structural equation relates the delay of investment to underlying credit frictions. The amplitude of credit frictions as predicted by the aftermaths of catastrophes are very correlated with long-horizon measures of financial development.

Despite being labeled as rare events, natural catastrophes are frequent in a large panel of countries. Regions² lying on major irregularities of a fault trace regularly experience tremors and associated tsunamis. Countries bordering the West-Pacific basin and the Atlantic basin suffer on a yearly basis from the passage of hurricanes and typhoons. In a nutshell, a very heterogeneous panel of countries is often concerned by natural calamities of large amplitude.

The catastrophe risk should be factored into decision-making in risky-prone areas. Theoretically, some instruments may alleviate the aftermath of a natural disaster. Insurance, aid contributions and debt rescheduling might provide ex-post resources. In practice, insurance is almost absent in the subsample of developing and under-developed countries. In addition, reimbursements concern mainly capital losses and does not mitigate losses from business disruption and indirect losses. Similarly, international assistance mainly provides immediate relief and neglects reconstruction or economic upturn. As such, countries in the wake of a shock first and foremost rely on reserves, debt relief and austerity plans.

These past few decades, human losses due to natural disasters have decreased quite substantially while economic damages have hovered, if not slightly increased. In parallel, an increasing attention has been devoted to direct damages and, more importantly, economic repercussions of natural disasters. Natural disasters might

²United States, Central America, Chile, Ecuador, Bolivia, Japan, China, Philippines, Indonesia, India, Pakistan, Iran, central Asia, Turkey, Greece are close to the more risky-prone areas.

move some countries away from their growth path. Despite the existence of studies dedicated to the economic consequences of natural disasters, no definite answers have emerged from the academic dispute. Countries with better institutions tend to suffer less from huge capital losses [Noy, 2009] and are able to maintain their level of trade [Gassebner *et al.*, 2006]. Among the keys to success stands financial development. Economies with a higher level of private credit are less prone to economic disruption. On the other hand, a country subject to frequent natural disasters benefits from a creative destruction process passing through R&D embodied in importations (Cuaresma *et al.* [2008] and Skidmore & Toya [2002]). To sum up, even for countries with bad institutions, the empirical findings are not very conclusive. Two stumbling blocks might explain the difficulty to identify common patterns following disasters. First, the explanatory power of reduced-form specifications suffers from the large heterogeneity across countries in the response to shocks. Second, data on natural disasters come mainly from declarations and reports, and induce biases when reported in addition to important truncations. As highlighted in Zylberberg [2010], the estimated amplitude of the economic disruption increases significantly when instrumenting the declarations of losses by objective measures. A low elasticity of economic shock to capital losses could then simply reflect censored declarations for the most affected economies, illustrating either an interest in concealing real exposure or simply a higher degree of seclusion.

The present paper focuses on shocks whose frequencies and amplitudes wedge into the space between classical productivity shocks and long-horizon convergence processes. This study is caught between the short-term³ and the long-horizon⁴ analysis.

To my knowledge, this project is the first paper focusing on misallocation of

³A huge strand of literature has used credit imperfections to understand business cycles. With no attempt at an exhaustive description, Bernanke & Gertler [1989], Bernanke *et al.* [1999] and Kiyotaki & Moore [1997] have pointed out the importance of credit frictions in the propagation of short-term shocks. Finally, Matsuyama *et al.* [2007] tries to reconcile both approaches.

⁴Regarding transition and development issues, Banerjee *et al.* [2005] provides a comprehensive review of the literature. This literature builds upon the seminal papers of Hall & Jones [1999], Piketty [1997] or Banerjee & Newman [1994]. More recently, Jeong & Townsend [2008] and Buera [2009] have tried to direct their attention to quantitative issues and calibrate their model on some transition economies.

resources after large natural disasters. The model is inspired by the quantitative-oriented literature on credit frictions, and aims at giving testable predictions for the empirical estimation. Accordingly, the model and its extensions can be solved in a closed-form recursion. The key ingredients which allow to alleviate the classical problems with heterogeneous agents - path-dependency, aggregation and the characterization of the steady-state distribution - are the following. Agents are only heterogeneous in their endowments. The CARA specification and the absence of uncertainty generates very simple *individual* dynamics. Even with those assumptions, the *aggregate* dynamics is complicated to characterize when agents differ in their capital endowment. The last restriction on the model imposes that an economy in the aftermath of a catastrophe is initially populated by only two kinds of agents - the unhappy few with a very low endowment and the happy lot. The unhappy few are infinitesimal, Taylor style, and the dynamics can then be approached at first-order. This assumption allows me to derive an approximation of the aggregate dynamics as if (i) the unhappy few were credit-constrained but under steady-state prices, (ii) the happy lot are unconstrained but under-accumulate because of a higher interest rate than the steady-state rate. Intuitively, responses are first-order for the majority of agents close to the steady-state and zero-order for the few agents displaced far below the steady-state. The theoretical framework borrows some features from Matsuyama *et al.* [2007], Buera [2009], Buera & Shin [2010], Angeletos & Calvet [2006], Krusell & Smith [1998], Quadrini [2000] and Greenwood *et al.* [2007], despite being simpler to a certain extent than any of them. Naturally, simplicity has its drawbacks. I consider here costly enforcement problems without any particular mechanism in mind. As such, I rule out - and this is rather ad-hoc - the existence of more complicated and sophisticated instruments or debt contracts. Besides, agents are not heterogeneous in their productivity, which could theoretically encompass the ability to mitigate against natural disasters. Finally, the natural disaster is modeled as an unanticipated shock driving a small proportion of agents away from the steady-state. I disregard preemptive behaviors as regards the occurrences of natural disasters, agents do not over-accumulate in order to smoothen future bad shocks.

The present paper estimates the influence of very large fluctuations over a large

number of events. A non-trivial empirical contribution of the present project is that it hinges on accurate and objective data on cyclone trails and earthquake tremors. Whereas studies drawing on reports from officials might be biased by misreports and censorships, the present paper alleviates both issues. More importantly, the dataset disaggregates a large event into many local impacts. For any given threshold, I can approach the proportion of the population affected by at least this level of energy. Going back to the theoretical framework, I can determine how many⁵ agents can be labeled as the unhappy few and relate directly the theoretical predictions with the empirics.

I present in section II. the theoretical framework and the evolution of macroeconomic aggregates as predicted by the model. I then discuss the strategies to construct a consistent dataset in section III.. The section IV. presents the empirical strategies and results. Extended results also are discussed in this section, focusing on a method to extract the underlying parameters related to credit rationing.

II. Theoretical model

In this section, I will describe the theoretical model. This model needs important features, the economy is a closed economy, there are no aggregate uncertainty (shocks are initial disturbances to the steady state) and agents are similar in every respect but their endowments. The theoretical part is organized as follows. I describe a standard Bewley model with infinitely-lived agents. I then characterize a degenerated steady state and study the importance of the initial distribution of capital and financial frictions in the convergence to the steady state. Finally, I illustrate the theoretical intuition with an analysis of impulse responses and propose a testable prediction of the model.

⁵a priori an infinitesimal proportion.

A. Hypotheses

The closed economy is composed of a mass of infinitely-lived agents. These agents are heterogeneous in terms of wealth but equally efficient at generating surpluses from the entrepreneurial activity or supplying efficient units of labor to their own firm. The economy is entirely deterministic⁶. Let us denote w_t the wealth of entrepreneur and $w \mapsto F_t(w)$ the distribution of wealth in the whole country at date t .

Entrepreneurs generate an income from their activity $f(k_t^i)$, depending only on capital inputs k_t^i . Importantly, I assume decreasing returns to scale, which create, in constrained economies, a gap between the ability to produce surpluses and the actual surpluses⁷.

As is common in these incomplete markets frameworks, I consider that only non-contingent instruments are traded. Agents can buy a quantity θ_t^i of bonds at period t with an interest rate r_t paid in $t + 1$. Insurance, cat bonds or any-kind of assets indexed on realizations of state of nature are excluded in this non-stochastic economy. Their existence in practice could attenuate the amplitude of initial disparities between affected and non-affected households/firms. Considering the market penetration of those contingent contracts in developing countries, this assumption is not utterly unreasonable. The assumption that agents borrow from one period to the next is more restrictive. More importantly, I do not model credit supply outside the country and assume it fixed and independent of credit constraints. The entrepreneur takes the interest rate r_t in the economy as given.

Let me detail some additional notations here. The only good in the economy can be consumed or used for production. Once an entrepreneur has rescheduled her debt, she can invest or consume c_t . Each agent maximizes her discounted utility derived from their consumption path. The utility function $u(\cdot)$ is a CARA function $u(c) = -e^{-c/\gamma}$, and is the same for everyone.

Let us turn to the credit frictions. Credit constraints arise from the impossibility for the investors to ensure contract enforcement in $t + 1$. At reimbursement date, the entrepreneur can indeed reimburse the amount specified in the contract or default

⁶Not only the aggregate dynamics is deterministic but also each individual dynamics.

⁷Marginal returns to a unit of capital will be higher for agents with few capital.

and flight with a part κ of the collateral. The part of collateral seized by the investor following a default is useless for them. As a consequence, the investors have no ex-post incentives to seize the capital and a renegotiation of the terms of the contract would be optimal for both parties. I assume that the investors can commit not to renegotiate the contract. There is no need for information asymmetry between the investors and the entrepreneurs about the real level of damaged capital and this latter characteristic will be common knowledge. Considering that agents can use their capital as collateral, the condition under which a default will occur specifies that instantaneous gain from deviation should be high enough:

$$(1 + r_t)\theta_t + k_{t+1} > (1 - \kappa)k_{t+1}$$

In this model, default is not considered as possible. Credit constraints will thus translate directly into a limit to the amount of debt required. Entrepreneurs can borrow up to the limit where they are willing to reimburse the amount specified in the contract. For simplicity, I omit the influence of the present interest rate on the credit constraint. This assumption can be made without loss of generality as long as we consider first-order approximations for the aggregate dynamics.

$$\theta_t \geq -\kappa k_{t+1}$$

B. Individual optimization

Consider $V_t(k_t, \theta_{t-1})$ the value function derived from the individual optimization at date t for an agent inheriting (k_t, θ_{t-1}) from period $t - 1$. The agent i maximizes the following program - where the superscript i is omitted:

$$\begin{aligned} V_t(k_t, \theta_{t-1}) &= \max_{(k_{t+1}, c_t, \theta_t)} \{u(c_t) + \beta V_{t+1}(k_{t+1}, \theta_t)\} \\ \text{s.t. } &\begin{cases} \theta_t \geq -\kappa k_{t+1} & (CC) \\ \theta_t + k_{t+1} + c_t \leq f(k_t) + (1 - \delta)k_t + (1 + r_{t-1})\theta_{t-1} & (BC) \end{cases} \end{aligned} \quad (M)$$

The concavity of the utility function ensures that the Slater conditions are verified

and the set of feasible allocations is non-empty as the no-debt contract does not bind the constraint (CC). The solution of the method of Lagrange multipliers generalized to inequality constraints is thus optimal following Karush-Kuhn-Tucker.

Proposition II.1. *The Euler equation can be written as follows:*

$$c_t = c_{t+1} - \gamma \ln(\beta(1 + r_t^*))$$

where

$$r_t^* = r_t + \frac{f'(k_{t+1}) - \delta - r_t}{1 - \kappa}$$

When the credit constraint binds, $\theta_t = -\kappa k_{t+1}$, otherwise, $f'(k_{t+1}) = r_t + \delta$.

Proof. The computations are developed in the appendix. □

Looking at the Euler equation, the credit constraints induce agents to smoothen their consumption at the effective returns on savings, a weighted sum of the marginal productivity of capital and the interest rate. In that respect, constrained agents decide to consume relatively less today as the returns on savings is higher for them than for unconstrained agents. This behavior tends to accelerate the process of capital accumulation.

C. Market clearing condition and steady state

The entrepreneurs are the only agents of the closed economy. Consequently, the equilibrium will be defined by the following conditions:

Definition II.1. *The equilibrium will be characterized by the individual and deterministic sequences $\{\theta_t^i, k_{t+1}^i, c_t^i\}_t$ and a deterministic sequence $\{r_t\}_t$ of interest rates such that:*

First, $\{\theta_t^i, k_{t+1}^i, c_t^i\}_t$ should solve the maximization program (M) for agent i ; second, the market price $\{r_t\}_t$ should be fixed such as to clear the bond market:

$$\int_0^\infty \theta_t^i di = 0$$

Intuitively, a steady state of this economy is very simple to characterize. In such a deterministic environment, the dynamics can be considered as monotonous, i.e. a drift of one of the state variable for one agent can not be compensated by a reverse drift for another agent. In short, an agent with a higher wealth will keep a higher wealth next period. Accordingly, a fixed point for the whole distribution needs to be a fixed point for almost each agent.

Proposition II..2. *A steady state is a fixed point for the distribution of (k^i, r) in the economy and is characterized for every agent by the following equations:*

$$\begin{cases} r_\infty + \delta = f'(k_\infty) \\ \beta(1 + r_\infty) = 1 \end{cases}$$

Proof. In the appendix. □

Infinitely-lived agents will deprive themselves and grow out of the credit trap. Once unconstrained, they are able to build the optimal level of capital - which happens to be the same for every agent in this stylized economy. Any initial distribution of capital degenerates into a point distribution. The reallocation of resources is optimal and credit does not play a role in the aggregate economy. As a consequence, unsurprisingly, the returns to capital are equal to the inverse of the discount factor and the capital stock is determined independently of the wealth distribution.

D. Aggregate dynamics and convergence

Let me study now the properties of the dynamic economy as a function of the initial distribution of wealth and the degree of credit constraints in the economy. To this purpose, I will consider a post-catastrophe version of this economy. At $t = 0$, the economy is composed of only two types of agents⁸, the happy lot and the unhappy few in proportion μ .

⁸The results derived in this section accommodate other initial distributions of wealth. The main assumption - which can not be relaxed - is the infinitesimal size of losers. Relaxing it would essentially impede any closed-form resolution.

The initial wealth of the affected agents will be ω and the wealth of unaffected entrepreneurs will be the steady-state wealth ω_∞ .

In order to solve the dynamic program under these initial conditions, I will consider a Taylor approximation at first order in μ . The usual approximations around a steady state consist in linearizations of a representative-agent program. Here, some agents are very far from the absorbing steady-state. Accordingly, a linearization of their individual dynamics is inconceivable. Nonetheless, as they are supposed to be an infinitesimal fraction of the overall population, an approximation at first-order can be described as follows; (i) the unhappy few may be credit-constrained but consider the steady-state prices and do not infer how their choices may affect market prices, (ii) the happy lot are driven away from the steady-state by the actions of the unhappy lot but their dynamics is still in the close neighborhood of this steady state. The resolution of the dynamics will illustrate this intuition. First, I will solve the dynamics for the “small economy” composed of the unhappy few under fixed prices. Second, I will incorporate the perturbation induced by the choices of the unhappy few in the program of the happy lot as an external shock. Finally, I will describe the world dynamics incorporating both components.

In a first instance, let us consider the dynamics of the unhappy few. The following lemma is key and drives the aggregate dynamics. Define for simplicity k_∞ and r_∞ :

$$\begin{cases} k_\infty = f'^{-1}\left(\frac{1-\beta}{\beta} + \delta\right) \\ r_\infty = \frac{1-\beta}{\beta} \end{cases}$$

Lemma II.3. *The dynamics can be characterized by the following recursion. First, consider the last period τ for which the agents are constrained. For every period t after τ , $k_{t+1} = k_\infty$. At period τ ,*

$$(1 - \kappa)k_{\tau+1} + c_0(w(k_{\tau+1})) - \gamma \ln \left(1 + \frac{\beta}{1 - \kappa} (f'(k_{\tau+1}) - f'(k_\infty)) \right) = w(k_\tau) \quad (\text{Ro})$$

with $c_0(w(k_{\tau+1})) = w_\infty + \frac{r_\infty}{1+r_\infty}w(k_{\tau+1})$ and $w : x \mapsto [(1 - \delta) - (1 + r_\infty)\kappa]x + f(x)$.

Then, the dynamics can be defined iterating backward with $k_{\tau-(n+1)}$ and $k_{\tau-n}$

related by the following equation where $c_n(w(k_{\tau-n})) = w(k_{\tau-n}) - k_{\tau-n+1}$.

$$(1 - \kappa)k_{\tau-n} + c_n(w(k_{\tau-n})) - \gamma \ln \left(1 + \frac{\beta}{1 - \kappa} (f'(k_{\tau-n}) - f'(k_\infty)) \right) = w(k_{\tau-(n+1)}) \quad (\text{Rn})$$

Proof. In the appendix. □

The dynamics reveals difficult to characterize in this general case. One of the reason comes from the fact that agents' choices are dependent on their past (backward-looking) but also on the anticipated consumption path (forward-looking). A simple way to keep tractability is to impose a constraint for consumption. If we add the constraint that consumption should be bounded to 0 and can not be negative, the dynamics may become simpler. The dynamics then consists in 3 segments, a first segment in which agents are credit-constrained and willing to maintain a consumption equal to 0 so as to grow out of those constraints, a second segment where they are still constrained but consume following an arbitrage between starvation and capital misallocation, and a third segment in which they are not constrained anymore. The following lemma imposes a condition (H) which ensures that agents will deprive themselves up to the point where they are unconstrained, i.e. the second segment disappears.

Lemma II.4. *Under the condition that*

$$w_\infty + \frac{r_\infty}{1 + r_\infty} (1 - \kappa)k_\infty - \gamma \ln \left(1 + \frac{\beta}{1 - \kappa} (f'(w^{-1}((1 - \kappa)k_\infty)) - f'(k_\infty)) \right) < 0 \quad (\text{H})$$

the dynamics can be expressed as follows:

$$(1 - \kappa)k_{t+1} = w(k_t)$$

as long as $w(k_t) < (1 - \kappa)k_\infty$ and $k_{t+1} = k_\infty$ once $w(k_t) \geq (1 - \kappa)k_\infty$.

Proof. This proposition is directly derived from the previous lemma. Under the condition (H), the consumption predicted by lemma II.3 will be negative for the last period for which agents are constrained. The constraint imposes then that it will

be equal to 0. Going backward, the Euler equation imposes then that consumption will be nil for all periods before. \square

Now, let us consider the first-order response of the happy lot to a shock on the credit markets. Denoting $\Theta_t = -\mu((1+r)\theta_{t-1} + \theta_t)$ where θ stands for the bond holdings of the unhappy few, Θ_t can be understood as the shock induced by their sudden demand for fundings. The response of the rest of the economy can be modeled as follows.

Lemma II..5. *Denote \tilde{x} the distance of the variable x to its steady state value. The dynamics of unaffected agents can be approached at first order by the following set of equations:*

$$\begin{cases} \tilde{c}_t + \tilde{k}_{t+1} = (1 + r_\infty)\tilde{k}_t + \Theta_t \\ \tilde{k}_{t+1} = -\eta_\infty \tilde{r}_t \\ \tilde{c}_t = \tilde{c}_{t+1} - \gamma \tilde{r}_t \end{cases}$$

where $\eta_\infty = -1/f''(f'^{-1}(r_\infty + \delta))$.

Proof. In the appendix. \square

Following a shock on very few agents, the aggregate dynamics can be approached by the zero-order evolution of the small country and the first-order response of the bigger country. The following proposition is a direct application of the previous lemmas.

Proposition II..6. *Consider the aforementioned distribution of wealth at period 0 - a very small proportion μ of agent inherits ω from the past while a proportion $1 - \mu$ inherits the steady-state endowment. \tilde{X} stands for the distance of X from its steady-state value. Denote k the capital accumulation of affected agents which constitutes the separate process described in lemma II..3. The dynamics is entirely determined by the following system:*

$$\begin{cases} \tilde{C}_t + \tilde{K}_{t+1} = (1 + r_\infty)\tilde{K}_t - \varepsilon_{t-1} \\ \tilde{C}_t = \tilde{C}_{t+1} + \frac{\gamma}{\eta_\infty}\tilde{K}_{t+1} + \mu_t \end{cases}$$

where ε_{t-1} and μ_t are disturbances relatively to the benchmark dynamics and ι is a dummy equal to 0 if the 0-bound for consumption is reached as described in lemma II.4.

$$\begin{cases} \varepsilon_{t-1} = -\mu [f(k_t) - f(k_\infty) - f'(k_\infty)(k_t - k_\infty)] \\ \mu_t = -\mu \left[\gamma \ln \left(1 + \frac{\beta}{1-\kappa} (f'(k_{t+1}) - f'(k_\infty)) \right) \iota + \frac{\gamma}{\eta_\infty} (k_{t+1} - k_\infty) \right] \end{cases}$$

Proof. In the appendix. □

This proposition states that the recovery will be quicker in unconstrained economies relatively to constrained economies. Naturally, this closed form recursion relies heavily on the fact that affected agents do not internalize the response of unaffected agents at first order. In particular, the condition under which the economy follows a representative-agent dynamics does not depend on the proportion of affected people (as long as it remains small). The role of the infinitesimal assumption can be understood as follows. Few Martians arrive on an Earth stabilized for ages at its steady-state. They are sufficiently small not to modify, from their point of view, the Earth economy. Accordingly, they behave as if they were at the steady-state but with low endowments. The condition under which the aggregate dynamics is representative-agent relies on the possibility for each individual - the fact that they are a group does not matter - to reach a representative-agent allocation. This capacity only depends on the distance between the steady-state endowment and theirs. In that sense, for a given wealth shock and as long as the proportion of outliers are small, the aggregate dynamics will be the further from the unconstrained dynamics for very intense shocks on very few people. Conversely, small differences between the two populations will be immediately absorbed.

The error term in the first equation can be understood as the cost on the aggregate wealth of imperfections driving some agents away from the optimal path. Two effects of credit constraints can be emphasized on the second equation, (i) the capital accumulation effect, (ii) the consumption-smoothing effect. The ideal demand for capital should increase but the effective demand for capital is limited by the borrowing constraints affecting the needy entrepreneurs. Basically, the interest rate will

not rise as much as it should be in a frictionless economy and some entrepreneurs will over-consume while others will under-invest compared to the counterfactual of the unconstrained credit markets. This under-accumulation of capital implies that the effective interest rate will be quite high for constrained agents. They mitigate this initial behavior by reducing their consumption today. Both effects wash away as soon as the unhappy few grow out of credit constraints and catch-up with the unconstrained dynamics.

E. Simulations and predictions

Let us analyze the shape of the impulse response predicted by the theoretical model. Building upon the proposition II.6, the system of equations can be written as follows:

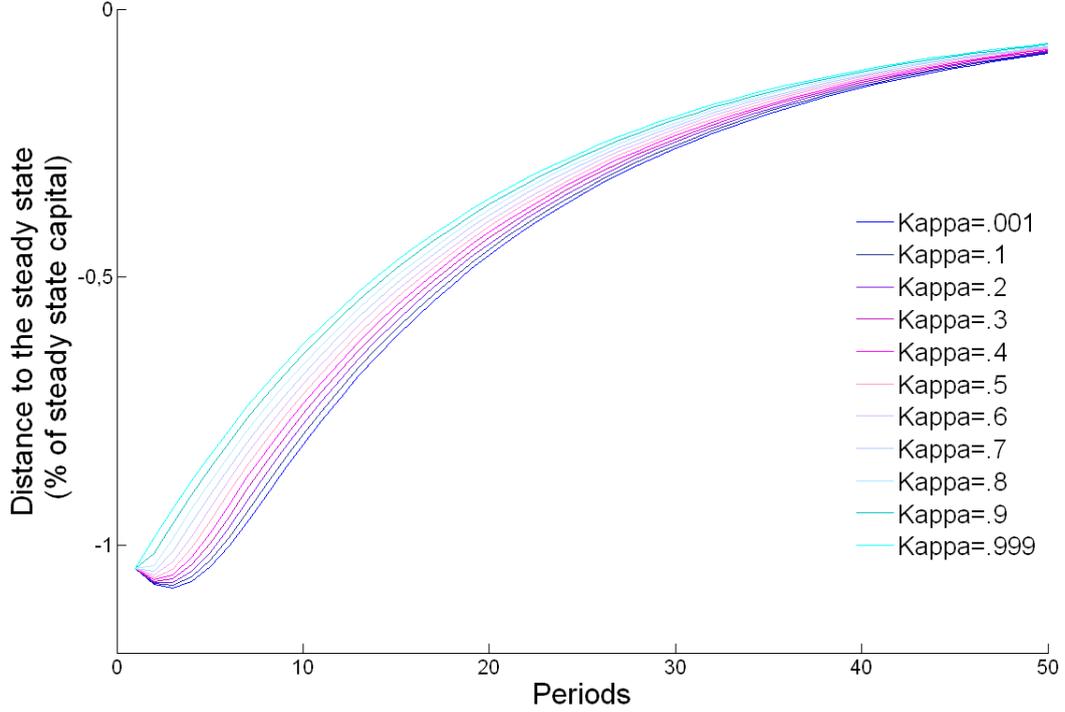
$$\tilde{X}_{t+1} = \begin{pmatrix} 1 + r_\infty & -1 \\ -(1 + r_\infty)\frac{\gamma}{\eta_\infty} & 1 + \frac{\gamma}{\eta_\infty} \end{pmatrix} \tilde{X}_t + \chi_t$$

where $\tilde{X}_t = \begin{pmatrix} \tilde{K}_t \\ \tilde{C}_t \end{pmatrix}$ is the vector of endogeneous variables, and $\chi_t = \begin{pmatrix} -\varepsilon_{t-1} \\ \mu_t + \frac{\gamma}{\eta_\infty}\varepsilon_{t-1} \end{pmatrix}$ the disturbance implied by the existence of financial frictions.

This model can be solved quite easily by iterating backward to relate to the initial capital and forward to converge to the steady state. Figure 1 illustrates the impulse responses of a set of different economies, the benchmark economy for which $\kappa \sim 1$, a set of slightly constrained economies and the heavily constrained economy $\kappa \sim 0$. As put into evidence by the comparison of these responses, the catching-up process is slower in constrained economies and investment comes later in the aftermaths of the catastrophe than in the benchmark case. With the calibration chosen here, the indirect shock is quite smaller than the direct shock. Accordingly, for readability concerns, I subtract for each trajectory the benchmark trajectory and plot the evolution of the indirect slack net of the direct effect in figure 2. The distance between the optimal trajectory and the constrained trajectory reaches a peak slightly after the shock and converges slowly to zero. The area between the curves and the horizontal axis gives a good idea of the extent to which an economy

is credit constrained.

Figure 1: Evolution of capital after a shock $\mu = 1\%$, $w = 0.1w_\infty$ on a set of different economies. Calibrated on the basis of an annual frequency with $f(k) = k^\alpha$, $\delta = .1$, $\beta = .96$, $\alpha = .5$, and $\gamma = 1$.



Coming back once again to the proposition II.6, the dynamic system can be written as follows:

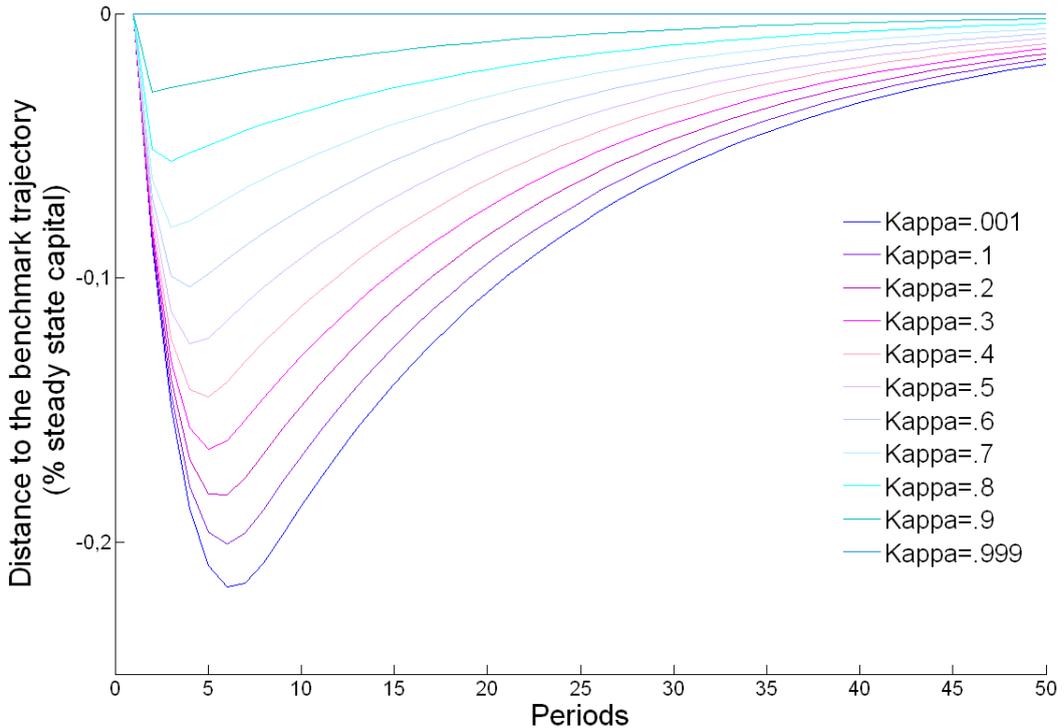
$$\begin{cases} \tilde{C}_t + \tilde{K}_{t+1} = (1 + r_\infty)\tilde{K}_t - \varepsilon_{t-1} \\ \tilde{C}_t = \tilde{C}_{t+1} + \frac{\gamma}{\eta_\infty}\tilde{K}_{t+1} + \mu_t \end{cases}$$

Differentiating the first equation and subtracting with the second one bring immediately:

$$\Delta\tilde{K}_{t+1,t+2} = r_\infty\Delta\tilde{K}_{t,t+1} + \frac{\gamma}{\eta_\infty}\tilde{K}_t + \mu_{t-1} - \Delta\varepsilon_{t-1,t}$$

This equation specifies that investment is delayed in subsequent periods once controlled for current investment in the case of a shock occurring at period t . In other words, the more constrained the economy and the larger the delay in the response of investment. As $\mu_{t-1} - \Delta\varepsilon_{t-1,t}$ is proportional to the degree of exposure of the economy μ and depends on the moment t_0 when the shock has struck the economy,

Figure 2: Evolution of capital compared to the benchmark evolution without frictions after a shock $\mu = 1\%$, $w = 0.1w_\infty$ on a set of different economies. Calibrated with $\delta = .1$, $\beta = .96$, $\alpha = .5$, and $\gamma = 1$.



the previous equation can be directly tested as follows:

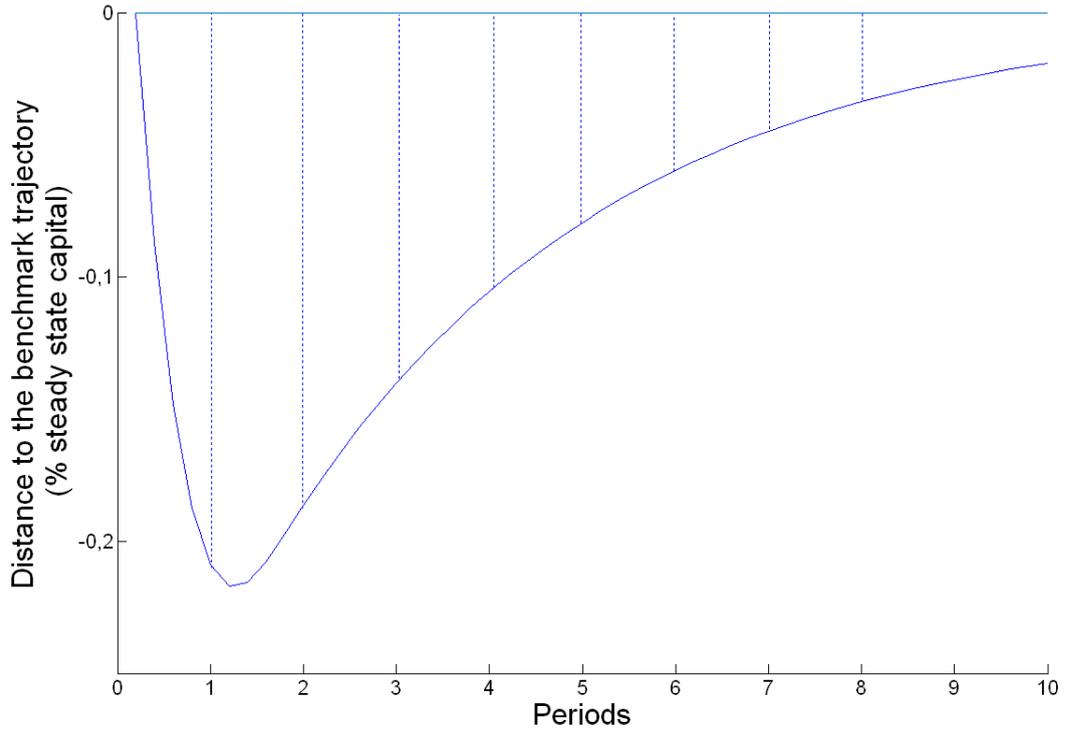
$$\Delta \tilde{K}_{t+1,t+2}^i = \zeta \Delta \tilde{K}_{t,t+1}^i + \zeta_k \tilde{K}_t^i + \zeta_e^i E_{t_0}^i + \nu_t^i$$

where ζ_e^i is the parameter of interest as a function of credit frictions κ in country i , $t - 1$ and the date of occurrence t_0 , and $E_{t_0}^i$ can be approached by the percentage of exposed agents in the country i when hit by the catastrophe. Note that ζ_e^i does not depend on the proportion of agents exposed but only on the extent to which they are exposed. The empirical construction will hinge on this hypothesis, extract for each economy an estimation of ζ_e^i and relate it with financial constraints. A graphical interpretation is given in figure 3: ζ_e^i is proportional, at period t for a shock occurring at $t = 0$, to the area between t and $t + 1$. Averaging this equation over all the potential shocks having occurred before $t - 1$,

$$\Delta \tilde{K}_{t+1,t+2}^i = \zeta \Delta \tilde{K}_{t,t+1}^i + \zeta_k \tilde{K}_t^i + \mathbb{E}_{t_0}[\zeta_e^i E_{t_0}^i] + \nu_t^i$$

Along the aftermaths of the shock, the estimation of $\mathbb{E}_{t_0}[\zeta_e^i E_{t_0}^i]$ then captures the average area above the curve shown in figure 3 (a linear combination of ε 's and μ 's).

Figure 3: Illustration of $\zeta_e^i E_{t_0}^i$ and $\mathbb{E}_{t_0}[\zeta_e^i E_{t_0}^i]$ as areas above the evolution of constrained economies.



III. Description of the data

In this paper, I will only detail the construction of the distribution of capital losses for each event. The careful reader might refer to Zylberberg [2010] for a panorama of the data sources and the construction of the local objective indicators of natural destructive power based on the local density of population.

I construct not only the first moment but also the heterogeneity of exposure across the population. In particular and this is relevant for applying the previous

theoretical framework, I can determine how much of the population of a country is affected by a certain threshold of energy.

The following section describes the construction of local measures of exposure and the aggregation method to construct catastrophe observations then country/year entries. In a second part, I give descriptive statistics on exposed countries and the average shock studied here.

A. Construction of the datasets

At first order, the amplitude of economic damages following a natural calamity in a certain zone ζ might be explained by three concurrent factors: the pure natural threat (the energy dissipated by the wind or seismic tremors), the economic assets at stake (accounting mainly for the physical capital but also for human capital) and the vulnerability of those assets (mitigation, prevention...).

A local measure of exposure

To simplify the analysis, for a catastrophe c in an area ζ , I will construct two proxies at a very disaggregated level for (i) the physical exposure $E^c(\zeta)$ and (ii) the quantity of assets at stake $A^c(\zeta)$.

For reasons of consistency between earthquakes and wind-based events, I rely on the energy dissipated in a certain area as a proxy for the physical exposure $E^c(\zeta) = e^c(\zeta)$. 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. These estimates need to be interacted with the economic activity at stake (ideally the physical productive capital). This quantity of assets will be approached by the local density of population $A^c(\zeta) = d_e(\zeta)$. This indicator is the only variable standing for economic activity and available at such a disaggregated level.

With these two proxies (available for each area of approximately 25 kms \times 30 kms crossed by a catastrophe), I construct

- the energy interpolated with by the local economic activity, $e^c(\zeta)d_e(\zeta)$ for a

particular area ζ and $\int e^c(\zeta)d_e(\zeta)d\zeta$ along the whole catastrophe, both normalized by the country population.

- economic activity exposed to at least a certain threshold of energy \bar{e} , $\mathbb{1}_{e^c(\zeta)\geq\bar{e}}d_e(\zeta)$ for a particular area τ and $\int \mathbb{1}_{e^c(\zeta)\geq\bar{e}}d_e(\zeta)d\zeta$ along the whole catastrophe, still normalized by the country population. The thresholds will be chosen as equivalents of the categories given to tropical typhoons by NOAA (from tropical storm, which will be assigned to \bar{e}_0 to category 5 typhoons which will be assigned to \bar{e}_5). Similarly, for earthquakes, the thresholds will be chosen such as to match the Richter scale and energy at the epicenter of a magnitude 5.5 (\bar{e}_0), 6 (\bar{e}_1), 6.5 (\bar{e}_2), 7 (\bar{e}_3), 7.5 (\bar{e}_4), 8 (\bar{e}_5) earthquake.

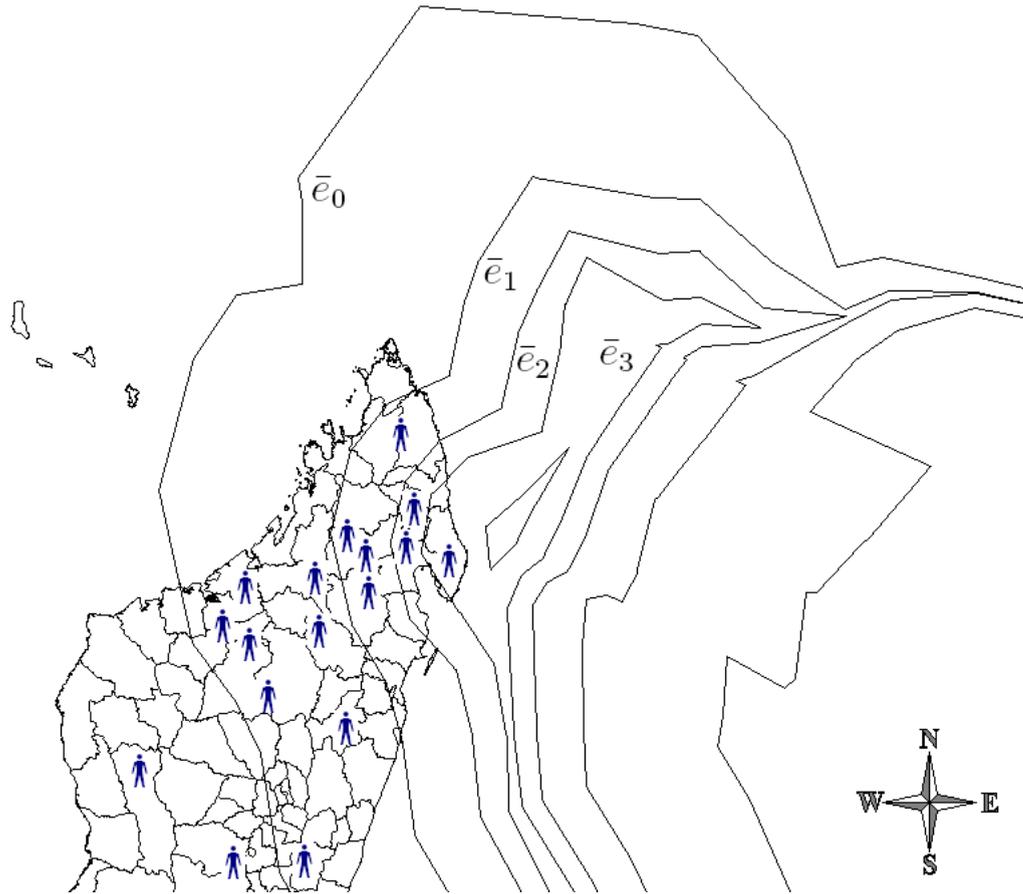
As the analysis will be led in relative terms, this construction does not assume economic activity per capita to be at the same level over the entire globe. Instead, the implicit assumption is that, in a given country, economic activity per capita does not depend on the density of population⁹.

Figure 4 gives an idea of how these indices are constructed using the example of cyclone Hary, passing through Madagascar in 2002. The lines represent level sets along which the wind is constant.

Briefly, Katrina (2005) was comparable to a dozen of tropical typhoons having affected Japan during the past decades both along the intensity and assets-at-stake dimensions. Mitigation and prevention go a long way into explaining the fact that Katrina has been more costly than all the tropical typhoons having landed on Japan over the last decade. Unfortunately, the vulnerability factor evoked in the preamble of this section remains mainly unobserved. A good indicator might be the penetration of private insurance. On the one hand, insurance companies are risk-averse and require a certain level of prevention and building regulations before setting up their activity durably in a country. On the other hand, the very presence of those firms gives the incentives for insureds to alleviate their exposure to large risk and reduce significantly the risk premia. This assumption imposes that the only disparity in mitigation mechanisms within a country come from the differences in exposure to

⁹this statement is likely to be violated, but accounting for a slight increase of economic activity per capita as a function of the density of population does not change the results.

Figure 4: Example for the construction of exposure - cyclone Hary (2002). The proportions of agents affected by \bar{e}_0 , \bar{e}_1 , \bar{e}_2 , \bar{e}_3 , \bar{e}_4 are respectively .88, .42, .18, .06, 0.



natural disasters. It is indeed sensible to see different levels of prevention in risky-prone areas than in safe zones. The regional exposure might provide a seemingly unbiased (but imprecise) measure of the regional vulnerability within a country.

Finally, I complement the objective measures with reports on immediate losses - mainly direct capital losses. EM-DAT¹⁰ is constructed using reports either from government officials or NGOs. The dataset will essentially fulfill the function of validity check for the constructed measures.

¹⁰EM-DAT: The OFDA/CRED International Disaster Database (www.emdat.be), Université Catholique de Louvain.

The aggregate measure of exposure

In order to match the macroeconomic datasets, I consider the annualized energy indexes constructed above and sum over all the catastrophes having occurred in a certain country i at a certain date t . In practice, I will weight each catastrophe by the number of months for which each catastrophe may have contributed to the output loss in the ongoing year i.e. the number of months between the catastrophe and the end of the year. I will add earthquakes and cyclones as apples and oranges. To be more precise, I treat the same way and aggregate assets destroyed by quakes of a certain category and cyclones of the “same” category. Once again, I invite the reader interested in how quakes may differ from cyclones to report to Zylberberg [2010] in which the differential impacts of those two events are documented along the different thresholds. The results presented here are robust to geological and wind events taken separately. In addition to the actual events, I create for each country at each point in time their expected losses assuming the stationarity of the natural threat distribution. This measure allows me to capture a potential response of the economy to its vulnerability rather than actual shocks and changes in exposure due to changes in densities of population in risky areas. It could play a role as the literature on idiosyncratic shocks in imperfect markets settings predict an over-accumulation of capital in the steady state as a precautionary motive. In practice, it will be almost completely absorbed by country-fixed effects.

Macroeconomic variables

In a nutshell, the macroeconomic variables are extracted from the World Development Indicators. The main variables of interest will be the GDP, average spread rate faced by the private sector and level of domestic credit for both the private and the banking sectors, the capital formation, bank deposits as well as important indicators accounting for openness, access to international relief, government expenditures. The indicators of financial development are constructed following the methodology proposed by Levine aggregating through loans, purchases of non-equity securities, trade credits and other accounts receivable given to the private sector, and sometimes

credit to public enterprises. Focusing on the supply-side, I also consider domestic credit provided by the banking sector including credit to the central government.

Despite predictable vulnerability, there are no real instruments designed to alleviate the economic slack in the aftermaths of these shocks. Insurance and aid contributions are rarely able to provide sufficient ex-post resources. Furthermore, both tend to respond to immediate needs and are not used to stimulate the economic upturn. The amounts are negligible except for very few regions (California, Florida and Japan do rely significantly on insurance) and events¹¹. As such, reserves, suspension of external debt payment and austerity plans are the main instruments used in practice to provide liquidity for reconstruction. I will try to control for these variables when assessing the recoveries in the aftermath of catastrophes.

B. Descriptive statistics

The dataset is a panel between 1980 and 2006 of approximately 180 countries¹², two third of them being actually in prey to either cyclones or earthquakes. The impression that only poor countries are affected by these catastrophes is misleading. The panel of countries regularly hit by those natural disasters is heterogeneous and include the richest economies but also developing economies or least-developed countries. That being said, the vulnerability of the latter and the economic resilience of the former justify that ex-post exposure seems to be far larger for Haïti or Philippines than Japan or Australia.

In this rectangular panel of 180 countries over 25 years, approximately 560 (resp. 520) country \times year entries are red-letter observations with a non-zero exposure to a cyclone (resp. earthquake). Naturally, these special years draw a very large spectrum

¹¹international mobilizations following the Haïti earthquake in 2009 and the tsunami of December 2004 are to be considered as outliers.

¹²To sum up, United States, Central America, Chile, Peru, Japan, China, Philippines, Indonesia experience frequent tremors due to their locations near the “Ring of Fire”. The other main threat is the eurasian fault affecting India, Pakistan, Iran, central Asia, Turkey and Greece. Cyclones, hurricanes or typhoons develop mainly in 5 basins (West-Pacific, East-Pacific, Indian, Australian, Atlantic). Caribbean islands, Mexico, Philippines, Vietnam or Madagascar are affected on a regular basis by very severe cyclonic storm. On the opposite, countries very close to the equator, inlands or bordered by cold seas are not exposed.

of shocks - both regarding the raw intensity and the number of people affected. Table 1 shows the average proportion of the population affected by each threshold for three samples of those shocks, the whole universe of entries, the subsample of entries containing at least events of category 2 and the same subsample for category 4 events. Two intuitions can be extracted from the table. First, intense catastrophes affect also larger fractions of a country. Second, even for those events, the average affected population is quite small relatively to the country population. The assumption that the proportion is infinitesimal will only be violated by few catastrophic years in Caribbean or Pacific islands.

Table 1: Descriptive statistics - the average catastrophic year

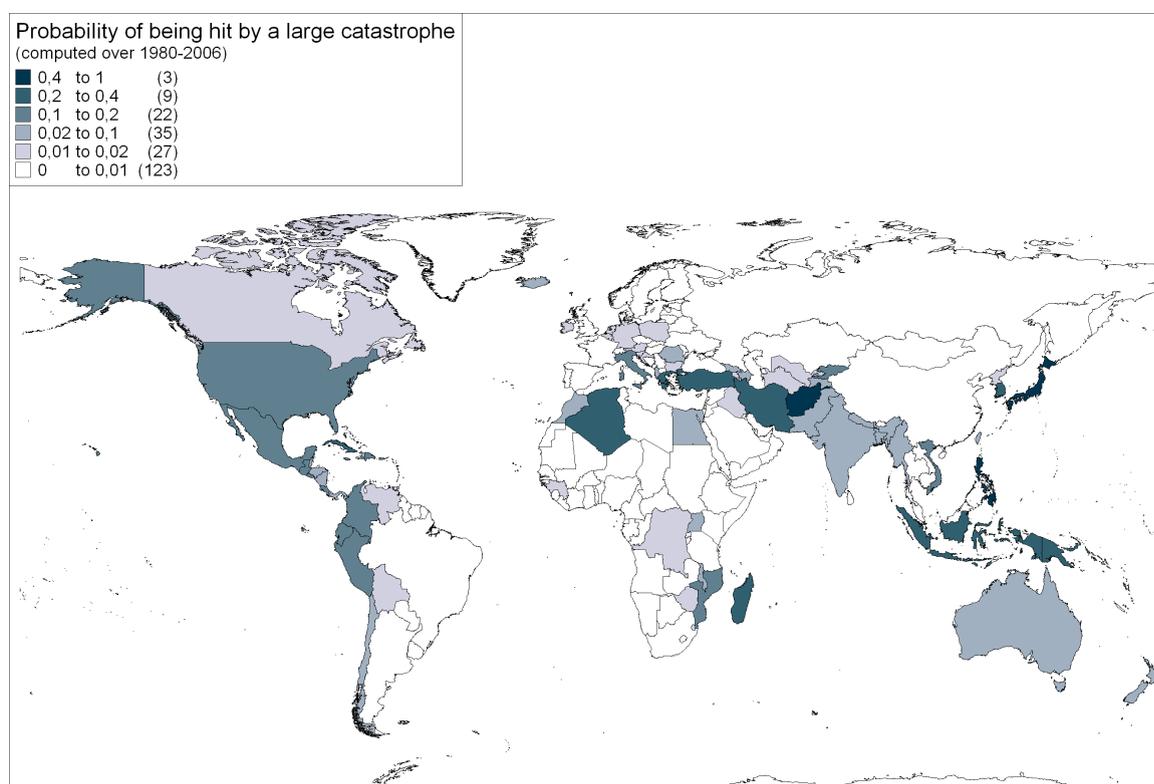
Threshold	Proportion of the population affected (%)				
	cat. 0	cat. 1	cat. 2	cat. 3	cat. 4
	<i>Cyclones, Typhoons, Hurricanes</i>				
Conditional on occurrence (566)	.41	.40	.21	.10	.05
Conditional on being cat. 2 (326)	.59	.58	.37	.18	.08
Conditional on being cat. 4 (50)	1.11	1.09	1.00	.90	.51
	<i>Earthquakes</i>				
Conditional on occurrence (524)	.18	.06	.04	.02	.01
Conditional on being cat. 2 (252)	.28	.12	.09	.04	.02
Conditional on being cat. 4 (94)	.40	.18	.14	.08	.06

The descriptive statistics aggregate events for the same country in the same year. Variables are thus the sum over the year of indices for each catastrophe corrected by the month of occurrence. In brackets, the number of year/country observations in which an event has occurred. 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.

Countries in risky-prone area are quite likely to endure a natural disaster of large economic magnitude. Based on EM-DAT, more than 60 (resp. 15) wind-based events and 100 (resp. 20) earthquakes are associated with direct economic damages larger than 1% (resp. 10%) of an affected country's GDP. Using objective data, the average exposure is of the same order of magnitude. In this section, I will define a *significant* catastrophe as a disaster affecting more than .1% of a country population. Almost 100 countries (for a total of 350 cyclones and 300 earthquakes) have experienced a significant cyclone or earthquake. Naturally, small islands are

over-represented but they do not account for the whole list. The map 5 represents the sample affected by these significant catastrophes. Remark first that all regions of the world are represented. Second, if this subsample of country differs from the subsample of unaffected countries by their exposure to natural disasters, they do not differ by economic or financial development as shown in figures F2 and F3 in the appendix. To sum up, not all countries are affected but the subsample of exposed economies seems to be representative.

Figure 5: Annual probability of being hit by a significant catastrophe (computed over the period 1980-2006).



In this paper, I will assume that the objective measures capture capital losses. That said, in practice, several channels help the propagation of an initial shock to the rest of the economy. A disaster can destroy transportation facilities in a country and freeze exports, leading to a quick deterioration of foreign debt levels. Agricultural economies might suffer from important crop losses. Finally, the destruction of public infrastructures might allegedly add to the initial chaos and incite agents to

undertake actions detrimental to the community (looting, back-market...). In this regard, both EM-DAT and the constructed measures are imperfect. Declarations in EM-DAT are likely to be a lower bound of the real economic exposure. Indirect losses are not reliably reported and the dataset suffers from censorship, truncation and declaration biases. On the other hand, the objective exposure only accounts for assets in the affected areas and does not include potential spillovers on direct surroundings. Furthermore, part of the damages incurred by cyclones or earthquakes is due to associated disasters - mudslides, floods, diseases.

IV. Empirical strategies and first results

A first and simple empirical test of the previous model is to study separately the evolution of output in the aftermath of either cyclones or earthquakes. The output is expected to be higher in the recovery of a large shock in frictionless economies than in constrained environments. The unlimited access to credit should allow those economies to allocate resources to deprived entrepreneurs. The second test focuses on credit markets and their evolution during the economic slack. The final specification extracts an estimation of financial frictions from the macroeconomic response of economies and the structural equation shown in the theoretical part. The predicted frictions are correlated with other indicators of financial development.

A. Evolution of output

Before turning to the main analysis, let me discuss the relationship between the objective measures of exposure, the financial development and measures of direct capital losses. In order to establish that financial development alleviates indirect losses, it is important to assume that financial development does not mitigate direct losses. The present study hinges on the assumption that capital losses may be directly related to objective measures but not to the financial environment. A simple story may contradict this hypothesis. Financial environment determines the penetration of insurance in a country, which influences in turn the building requirements and prevention. An even simpler mechanism would come from the fact that

Table 2: Declared damages predicted by objective measures and the financial development

Role of credit on direct losses						
Specifications	Declared damages (% of GDP)					
	OLS	OLS	OLS fe	OLS	OLS	OLS fe
Objective index (cat 0)	1.34 (.124)**	1.46 (.231)**	1.31 (.307)**			
Objective index (cat 1)				1.21 (.136)**	1.22 (.248)**	1.22 (.326)**
FD		.000 (.001)			-.000 (.001)	
FD×index (cat 0)		-.299 (.445)	.369 (.629)			
FD×index (cat 1)					.021 (.473)	.544 (.660)
Year fixed effects			Yes			Yes
Country fixed effects			Yes			Yes
Observations	5426	5426	5426	5426	5426	5426

Significantly different than zero at [†] 90% confidence, * 95% confidence, ** 99% confidence. The observations are here country/year. Declared damages are divided by the current GDP. Variables are the sum over the year of indices for each catastrophe corrected by the month of occurrence. The indices correspond to the percentage of the population affected by a category 0 event (resp. category 1), i.e. a cat. 0 (resp. cat. 1) typhoon or a magnitude 5.5 (resp. 6) earthquake for a given year in a given country. Results are robust to the use of other thresholds. FD stands for financial development, captured by the percentage of domestic credit over GDP averaged over the period 1980-2006.

financially developed country are more risk-averse, more informed or have better technologies.

This assumption is very strong and needs to be tested. To this purpose, I use direct damages reported in EM-DAT for wind storms and earthquakes and see if those direct economic losses can be predicted by objective exposure and financial development. The observations are country/year and I compare aggregate declared damages to the proportion of population hit by, at least, events of category 0 or 2 for a country over the year. Table 2 shows that objective estimates are very good predictors of declared damages. 1% of the population affected by a category 0 event generates direct losses of the order of 1 GDP point. Financial development does not

play any role, either in changing the average reports nor the amplitude of capital losses for a given level of natural threat. This analysis is robust to the addition of macroeconomic controls and the use of other objective indicators. Overall, it gives support to the hypothesis that financial development does not mitigate *direct* damages - capital losses or immediate disruption.

Table 3: Impact of natural disasters on immediate output

Specifications	Role of credit on indirect losses			
	GDP growth (t)			AB
	OLS	OLS	OLS	
Shock \times FD	.028 (.015) [†]	.035 (.015)*	.031 (.015)*	.021 (.009)*
Shock	-1.69 (.726)*	-2.08 (.748)**	-2.08 (.761)**	-1.32 (.417)**
Propensity \times FD	-.002 (.001)	.000 (.001)	-.001 (.001)	
Propensity	.058 (.091)	.041 (.093)	.040 (.093)	
FD	.003 (.003)	.000 (.004)	.001 (.004)	
Gov. cons. ($\%, t - 1$)		-.053 (.017)**	-.052 (.017)**	-.267 (.120)*
Reserves ($\%, t - 1$)		3.36 (.785)**	3.35 (.799)**	12.6 (6.06)*
Exports ($\%, t - 1$)		.026 (.006)**	.015 (.005)**	.001 (.005)
Cap. form. ($\%, t - 1$)			.071 (.028)**	.061 (.074)
Current account ($\%, t - 1$)			-.025 (.030)	.008 (.049)
GDP growth ($t - 1$)	.339 (.040)**	.301 (.044)**	.272 (.049)**	.133 (.048)**
Year fixed effects				Yes
Country fixed effects				Yes
Observations	3180	3006	2797	2957

Significantly different than zero at [†] 90% confidence, * 95% confidence, ** 99% confidence. (AB) is a specification using Arellano-Bond System GMM estimator with 2-periods lags. The dependent variable is the GDP growth for the ongoing year. The exposure is the annual exposed population to earthquakes or wind-based events (of category 1) divided by the population. Propensities are computed as the percentage of the population in risky zones at each date. FD stands for financial development, captured by the percentage of domestic credit over GDP averaged over the period 1980-2006.

Let us turn to the analysis of *indirect* losses of output. Denote A_t^i the measure of effective exposure to natural disasters, i.e. the percentage of the population

exposed to a certain threshold \bar{e} , y_t^i the immediate output growth and E_t^i the expected exposure. The average credit of the private sector over the period (as a percentage of GDP) FD^i will be used to approach the level of credit constraints in the country i in line with Levine.

The basic equation which will be estimated is as follows:

$$y_t^i = \alpha A_t^i + \gamma A_t^i \times FD^i + \alpha_e E_t^i + \gamma_e E_t^i \times FD^i + \zeta y_{t-1}^i + \beta \hat{X}_{t-1}^i + \varepsilon_t^i$$

This allows me to untangle the raw effect α of catastrophe from the credit-channel effect γ . α captures the average effect of catastrophe whereas γ accounts for the differential response to the shock along the financial development characteristic. Several strategies may help to refine the definition of the counterfactual growth had the economy not been disturbed by a shock. In a first specification, a broad set of controls X_{t-1} in $t - 1$ might prove sufficient to capture this counterfactual. I will consider gross capital formation, current account, exports, government consumption and reserves to account for shocks and government responses. In a second instance, I will also add fixed effects to this dynamic estimation and replace the simple OLS by the Arellano-Bond difference GMM estimator using lags up to 2 periods. The choice of one or the other specification will not change the results, the same can be noticed for the set of controls.

Table 3 documents a first stylized fact in line with the intuitions developed earlier. The economic slowdown is larger in constrained economies. The interpretation of the table is straightforward: on average, an additional percent of the economy exposed to the equivalent of a category-1 cyclone¹³ triggers an immediate output slack of approximately 1.5 points of GDP growth. This slowdown is alleviated by .25 points of GDP growth for each additional 10 percent of domestic credit on average in the economy. Accordingly, the last decile economy in terms of financial development loses 2 points of GDP growth while the first decile economy does not suffer from any economic slack. Table T2 in the appendix displays the results for different thresholds. In particular, the larger the thresholds the larger the effects.

¹³wind speed between 119 and 153 km/h.

This pattern is not surprising. Putting aside the differential impact along the level of financial institutions, the direct impact of having a percent of the population exposed is naturally increasing in the threshold chosen. As documented in table T3, a percent of the population affected by a cat-0 (resp. cat-1, cat-2, cat-3, cat-4, cat-5) earthquake or typhoon creates a decline in the GDP growth of .99 points (resp. 1.17, 1.91, 2.00, 4.49, 14.2).

This stylized fact does not identify credit constraints as the channel through which a credit-constrained economy lags behind. It can also indicate different responses in countries with a more developed financial environment due to unobserved characteristics such as mitigation institutions or access to financial support¹⁴. In the following tests, I focus more directly on the evolution of investment and the credit markets following the catastrophe.

B. Evolution of investment, deposits and interest rates

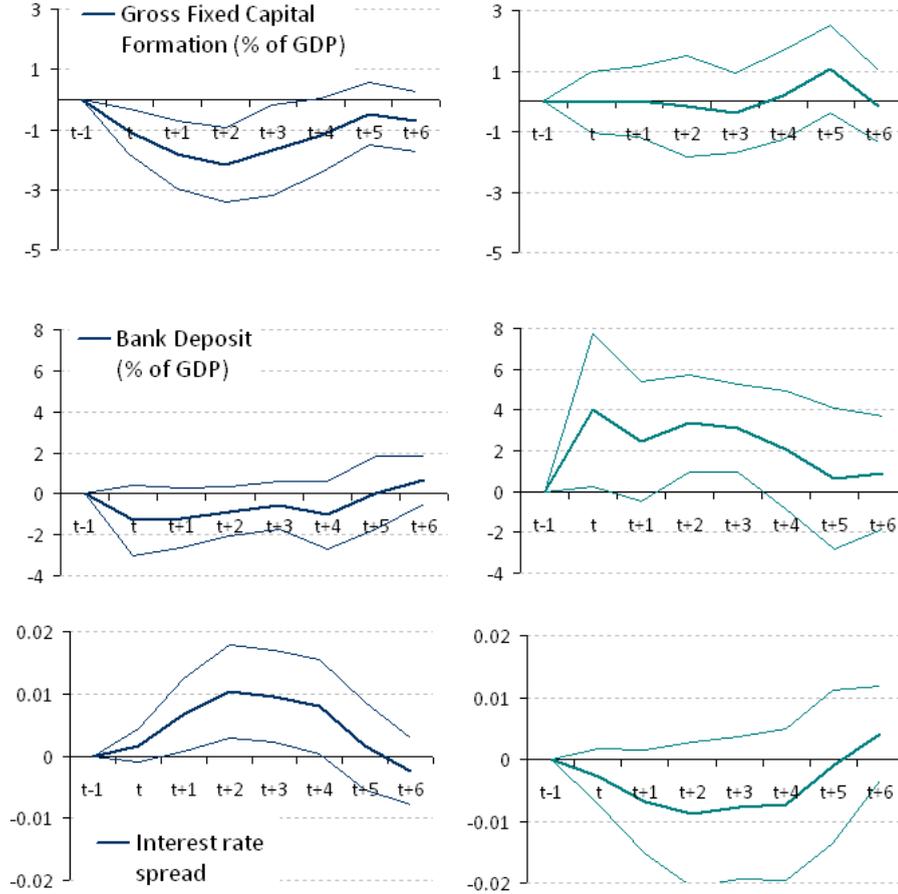
In this part, I will analyze the evolution of investment and domestic credit in the aftermath of a catastrophe. To this purpose, I will consider separately capital formation, deposits and interest rate spreads. The following estimation is the basis for the construction of the empirical impulse response:

$$y_t^i = \sum_{l=0}^L (\alpha_l A_{t-l}^i + \gamma_l A_{t-l}^i \times FD^i) + \zeta y_{t-L}^i + \beta \hat{X}_{t-L}^i + \nu_i + \mu_t + \varepsilon_t^i$$

As in the previous case, the estimation will be done with the Arellano-Bond difference GMM estimator. The results are reported in table T1 in the appendix. For readability concerns, the results are also plotted as impulse response functions for two benchmark economies, the first-decile economy in terms of financial development (10 percent of domestic credit over GDP over the period 1980-2006), and the last decile economy (90 percent of domestic credit over GDP over the period 1980-2006) in figure 6 for gross fixed capital formation, bank deposits and interest rate spreads. Figure F1 in the appendix displays the evolutions of gross capital formation and financial system deposits as robustness checks. The patterns are extremely similar.

¹⁴Remark that I control for international aid, remittances and debt rescheduling when reported.

Figure 6: Separate evolutions of fixed capital formation, bank deposits and interest rate spread (.01 corresponds to 1% or 100 bps) after a catastrophe (confidence interval at 90%). Calibrated on two countries with: average financial development of 10% (left panel), average financial development of 90% (right panel).



Let us focus on the volume of credit and investment in the economy. There is a gap both for the volume of deposits and the volume of fixed capital formation between the first decile economy and the last decile economy in terms of financial development. This gap corresponds roughly to 3 points of GDP during the 3-4 years following the catastrophe. For each percent of the economy exposed, the additional 10% percents of loans provided to the private sector are associated with a rise of investment of .20 points of GDP. In economies with few financial frictions, the investment rises slowly following a large shock and deposits increase significantly. On the other hand, investment decreases in constrained economies and deposits stagnate. These features are summed up in figure 6 (F1 in the appendix for slightly different

definition of capital formation or deposits) for the aftermaths of a catastrophe of category 1 affecting 1% of the population. Whereas the private credit reacts positively to a shock on capital in an economy with a high initial level of credit, credit plunges in environments with low initial levels. Both responses fade away after 3-4 years.

The analysis of volumes seems to be supported by the evolution of prices. Focusing on the spread rate between lending rate and treasury bills, figure 6 shows an increase of this spread in countries with high financial frictions. Those economies experience an increase of this spread up to 100 bps for a catastrophe of category 1 affecting 1% of the population. This additional premium as for the volume of investment disappears after 4 years. The picture is very different for financially-developed economies. Each additional percent of loans provided to the private sector reduces this increase by 10 bps. Those economies thus experience a stagnation of spread rates.

The results are consistent with the interpretation that affected entrepreneurs might fall in a credit trap in economies where borrowing constraints are very tight. Let us remark that the back-of-the-envelope computation of capital losses necessary to justify a decrease of 2% of GDP (associated with a catastrophe of category 1 affecting 1% of the population) is in line with the level of additional investment observed in financially developed economies. The increase of investment following a 1%-catastrophe in countries without credit frictions is estimated to be of the same order of magnitude of capital losses - approximately 10% of a country's GDP shared among the first 3-4 years after the shock.

Overall, the separate evolutions of the level of investment, the output and the price of capital corroborate the dynamics suggested by the theoretical framework. Notice that these results are robust to other definitions of financial development, taking the initial value of domestic credit rather than the average for instance, or credit supplied by banking institutions. Furthermore, they are not driven by a higher economic development in general in financially-developed economies, as the regressions are robust to the addition of the interaction of shocks with GDP per capita. I do not account for redistribution performed by a central government

here. Naturally, the state is an important actor alleviating misallocation of capital, technology or labor in the economy. This channel as well as access to international funds are left for future work.

C. Structural estimation

The previous empirical specifications point to a large economic slack in credit constrained economies. In this section, I propose a direct estimation of the theoretical model in order to establish the access to credit as the prominent factor in the recovery. To this purpose, consider the delay-equation extracted from the theoretical framework.

$$I_{t+1}^i = \zeta I_t^i + \zeta_k \tilde{K}_t^i + \mathbb{E}_{t_0}[\zeta_e^i E_{t_0}^i] + \nu_t^i$$

Investment I_{t+1} is delayed for economies with large financial frictions and $\mathbb{E}_{t_0}[\zeta_e^i E_{t_0}^i]$ captures the extent to which investment lags behind between $t+1$ and t for a shock having intervened at t_0 ($t-1$ or before). For simplicity, I will assume the following functional form for the disturbance term:

$$\mathbb{E}_{t_0}[\zeta_e^i E_{t_0}^i] = \chi_e^i \sum_{\tau=1}^8 E_{t-\tau}^i$$

The tested equation will thus be:

$$I_{t+1}^i = \zeta I_t^i + \zeta_k \tilde{K}_t^i + \chi_e^i \sum_{\tau=1}^8 E_{t-\tau}^i + \nu_t^i$$

and the test will be performed with the Arellano-Bond difference GMM estimator with 2 lags, considering gross (fixed) capital formation for I , normalized GDP per capita to capture K and the sum of the population affected by a category 1 event during the 8 years including $t-1$. Following these estimations, I extract the country-level estimations of χ_e^i . Table T4 shows the estimates of χ_e^i for a panel of 60 countries having suffered from at least two category-1 events between 1980 and 2006. Remark that the United States, Iceland and Canada are among the best students while

Bhutan, Madagascar, and Fiji are the countries in which investment is the most delayed. For more surprising results, Nepal and Japan inherit from unexpected values - potentially inflated for the latter, deflated for the former. Comparing this measure with different indicators of financial development, table 4 illustrates that it is negatively correlated with the average private credit in the economy (whether supplied by banks alone or together with other financial institutions). In parallel, the measure is positively correlated with the concentration of banks and negatively with insurance penetration but only for non-life premiums. Countries where investment is delayed have small financial and insurance sectors (in particular for non-life products) and a high bank concentration. These correlations are also plotted in figure 7.

Table 4: Correlations between the parameter extracted from the structural model and other indicators of financial development

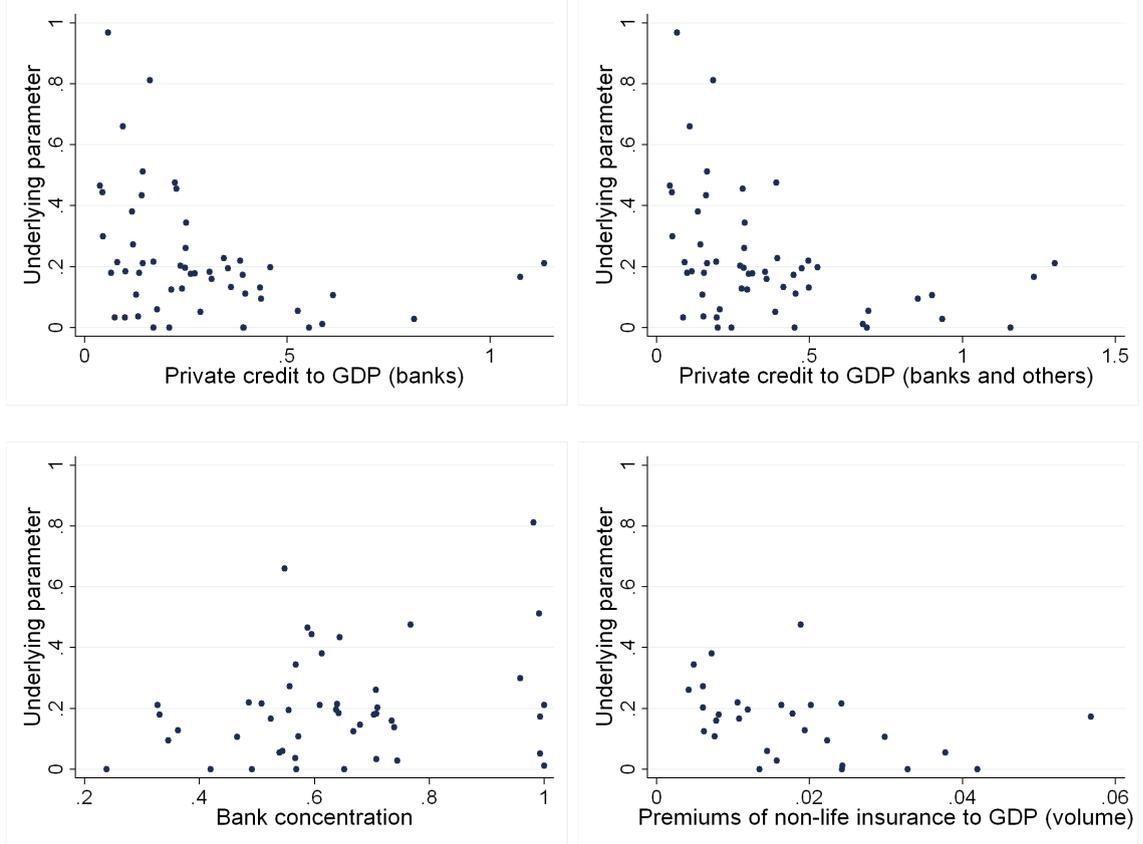
Computed with	Structural parameter χ_e^i					
	Gross capital formation			Gross fixed capital formation		
	correlation	p-value	obs.	correlation	p-value	obs.
Private domestic credit (banks)	-.294	(.029)	55	-.344	(.011)	54
Private domestic credit (all institutions)	-.337	(.011)	55	-.377	(.005)	54
Concentration of banks	.304	(.035)	48	.265	(.071)	47
Non-life insurance volumes	-.237	(.198)	31	-.400	(.031)	29
Life insurance volumes	-.022	(.903)	31	-.061	(.749)	29

The indicators of financial development are the average over the period 1980-2006 of credit supplied by banks to the private sector, credit supplied by all financial institutions, concentration of banks and premiums volume to GDP for non-life and life insurance. The number of observations are thus limited by the availability of those indicators and the computation of the structural parameters for which I keep countries having been affected at least twice during the period. The first column depicts estimations computed using the evolution of gross capital formation, the second one uses gross fixed capital formation.

In the next lines, I will go beyond the raw correlation and discuss the shape of these figures, comment the small number of observations and explain absurd

observations.

Figure 7: Correlations between the measured lag in investment in the aftermaths of catastrophes and classic indicators, i.e. domestic private credit supplied by banks, by banks and other financial institutions, bank concentration and insurance penetration.



Financial development plotted in figure 7 seems to be a hyperbolic function of the estimated level of frictions in the economy. In an economy where all agents willing to borrow are constrained, κ can be interpreted as the leverage which drives the level of domestic credit supplied to the private sector. In parallel, χ_e^i can roughly be expressed as a polynomial function of $\frac{1}{1-\kappa}$. This simple intuition gives support to the empirical observation. The analysis of the curves for bank concentration or insurance premiums would be more adventurous.

Two different sources contribute to the attrition in the estimation of the relationship between each country's χ_e^i and state-of-the-art indicators of financial development. First, these indicators are not always available in particular for insurance

premiums and bank concentration. Second, only economies having suffered from two shocks between 1980 and 2006 are kept for the estimation - which reduces drastically the panel of countries (almost half of the sample of countries affected by large catastrophes disappear).

Theoretically, χ_e^i should range from 0 to 1. The estimations of χ_e^i abstracts away from these limits in two extreme cases. When the recovery is even faster than predicted for an economy without frictions, χ_e^i is negative. Colombia and, less surprisingly, the United States are in this situation. These economies might receive large capital flows from the rest of the world, explaining then the observed investment boost. At the other end of the spectrum, some economies recover slower than predicted in the worst-case scenario. Panama and Bhutan are among those countries. Other indirect repercussions than credit squeeze might explain this pattern, state bankruptcy, exacerbated tensions and long business disruptions are good candidates.

V. Conclusion

This article has explored theoretically and empirically the intuition that financial frictions amplify the economic slack following natural disasters. In credit-constrained environments, the evolution of domestic credit follows the opposite pattern of what the optimal response of the economy would be. This distortion has repercussions on immediate recovery and tends to freeze the catch-up process. Investment lags behind during 3 to 5 years.

The macroeconomic analysis of a large panel of economies should theoretically alleviate concerns about external validity of the results. That being said, the extraction of underlying credit constraints in the aftermaths of cyclones and earthquakes might capture very different fundamentals than those at stake in a normal and quiet state. In particular, international assistance and heavy state intervention might drive the estimates far from fundamentals of the private markets.

While I exploit capital markets imperfections in this study, the results point

out the importance of unconstrained reallocation mechanisms in general. The state capacity to redistribute resources might alleviate the distortion induced by failing capital markets. In practice, distorted capital markets are often accompanied by weak states and it is difficult to untangle the failure of decentralized markets from the failure of the government. Finally, labor markets should also play a role as a large fraction of the population might experience business disruption and partial unemployment. Further research could examine the importance of labor market frictions and determine which imperfections trigger the largest economic distortions.

References

- AGHION, PHILIPPE, & BOLTON, PATRICK. 1997. A Theory of Trickle-Down Growth and Development. *The Review of Economic Studies*, **64**(2), 151–172.
- AGHION, PHILIPPE, HOWITT, PETER, & MAYER-FOULKES, DAVID. 2005. The Effect of Financial Development on Convergence: Theory and Evidence. *Quarterly Journal of Economics*, **120**(1), 173–222.
- ALBALA-BERTRAND, J. M. 1993. Natural disaster situations and growth: A macroeconomic model for sudden disaster impacts. *World Development*, **21**(9), 1417–1434.
- ANGELETOS, GEORGE-MARIOS, & CALVET, LAURENT E. 2006. Idiosyncratic Production Risk, Growth, and the Business Cycle. *Journal of Monetary Economics*, Feb.
- BANERJEE, ABHIJIT V., & NEWMAN, ANDREW F. 1994. Poverty, Incentives, and Development. *The American Economic Review*, **84**(2), 211–215.
- BANERJEE, ABHIJIT V., DUFLO, ESTHER, AGHION, PHILIPPE, & DURLAUF, STEVEN N. 2005. Growth Theory through the Lens of Development Economics. vol. Volume 1, Part 1. Elsevier.
- BERNANKE, BEN, & GERTLER, MARK. 1989. Agency Costs, Net Worth, and Business Fluctuations. *The American Economic Review*, **79**(1), 14–31.
- BERNANKE, BEN S., GERTLER, MARK, GILCHRIST, SIMON, TAYLOR, JOHN B., & WOODFORD, MICHAEL. 1999. The financial accelerator in a quantitative business cycle framework. vol. Volume 1, Part 3. Elsevier.
- BUERA, FRANCISCO J. 2009. A dynamic model of entrepreneurship with borrowing constraints: theory and evidence. *Annals of Finance*, **5**(3-4), 443–464.
- BUERA, FRANCISCO J., & SHIN, YONGSEOK. 2006 (Dec.). *Financial Frictions and the Persistence of History*.

- BUERA, FRANCISCO J., & SHIN, YONGSEOK. 2010. Financial Frictions and the Persistence of History: A Quantitative Exploration. *National Bureau of Economic Research Working Paper Series*, No. **16400**(Sept.).
- BUERA, FRANCISCO J., KABOSKI, JOSEPH P., & SHIN, YONGSEOK. 2009 (Apr.). *Finance and Development: A Tale of Two Sectors*. <http://econpapers.repec.org/paper/nbrnberwo/14914.htm>.
- CHINN, MENZIE D., & ITO, HIRO. 2007. Current account balances, financial development and institutions: Assaying the world "saving glut". *Journal of International Money and Finance*, **26**(4), 546–569.
- CUARESMA, CRESPO, HLOUSKOVA, & OBERSTEINER. 2008. Natural Disasters As Creative Destruction? Evidence From Developing Countries. *Economic Inquiry*, **46**(2), 214–226.
- DE MEL, SURESH, MCKENZIE, DAVID, & WOODRUFF, CHRISTOPHER. 2008. Returns to Capital in Microenterprises: Evidence from a Field Experiment. *Quarterly Journal of Economics*, **123**(4), 1329–1372.
- GASSEBNER, MARTIN, KECK, ALEXANDER, & TEH, ROBERT. 2006. The Impact of Disasters on International Trade. *SSRN eLibrary*, Mar.
- GHOSH, PARIKSHIT, MOOKHERJEE, DILIP, & RAY, DEBRAJ. 2000. Credit Rationing in Developing Countries: an overview of the theory. *in D Mookherjee and D Ray (eds) A Reader in Development Economics*, **11**, 383–401.
- GREENWOOD, JEREMY, SANCHEZ, JUAN M., & WANG, CHENG. 2007. Financing Development: The Role of Information Costs. May.
- HALL, ROBERT E., & JONES, CHARLES I. 1999. Why Do Some Countries Produce So Much More Output Per Worker Than Others?*. *Quarterly Journal of Economics*, **114**(1), 83–116.
- HEATHCOTE, JONATHAN, STORESLETTEN, KJETIL, & VIOLANTE, GIOVANNI L. 2009. Quantitative Macroeconomics with Heterogeneous Households. *National Bureau of Economic Research Working Paper Series*, No. **14768**(Mar.).

- JEONG, HYEOK, & TOWNSEND, ROBERT. 2008. Growth And Inequality: Model Evaluation Based on an Estimation-Calibration Strategy. *Macroeconomic dynamics*, **12**(S2), 231–284.
- KIYOTAKI, NOBUHIRO, & MOORE, JOHN. 1997. Credit Cycles. *The Journal of Political Economy*, **105**(2), 211–248.
- KRUSELL, PER, & SMITH, ANTHONY A. 1998. Income and Wealth Heterogeneity in the Macroeconomy. *The Journal of Political Economy*, **106**(5), 867–896.
- LEVINE, ROSS. 1997. Financial Development and Economic Growth: Views and Agenda. *Journal of Economic Literature*, **35**(2), 688–726.
- MALIAR, LILIA, MALIAR, SERGUEI, & VALLI, FERNANDO. 2010. Solving the incomplete markets model with aggregate uncertainty using the Krusell-Smith algorithm. *Journal of Economic Dynamics and Control*, **34**(1), 42–49.
- MANOVA, KALINA. 2008. Credit constraints, equity market liberalizations and international trade. *Journal of International Economics*, **76**(1), 33 – 47.
- MATSUYAMA, KIMINORI, GERTLER, MARK, & KIYOTAKI, NOBUHIRO. 2007. Aggregate Implications of Credit Market Imperfections [with Comments and Discussion]. *NBER Macroeconomics Annual*, **22**, 1–81.
- NOY, ILAN. 2009. The macroeconomic consequences of disasters. *Journal of Development Economics*, **88**(2), 221–231.
- PIKETTY, THOMAS. 1997. The Dynamics of the Wealth Distribution and the Interest Rate with Credit Rationing. *The Review of Economic Studies*, **64**(2), 173–189.
- QUADRINI, V. 2000. Entrepreneurship, Saving, and Social Mobility. *Review of Economic Dynamics*, **3**(1), 1–40.
- RAJAN, RAGHURAM G., & ZINGALES, LUIGI. 1998. Financial Dependence and Growth. *The American Economic Review*, **88**(3), 559–586.
- RASMUSSEN, TOBIAS. 2004. Macroeconomic Implications of Natural Disasters in the Caribbean. *SSRN eLibrary*, Dec.

- SKIDMORE, MARK, & TOYA, HIDEKI. 2002. Do Natural Disasters Promote Long-Run Growth? *Economic Inquiry*, **40**(4), 664–687.
- TOYA, HIDEKI, & SKIDMORE, MARK. 2007. Economic development and the impacts of natural disasters. *Economics Letters*, **94**(1), 20–25.
- ZYLBERBERG, Y. 2010. Natural natural disasters and economic disruption. *Working Paper*, May.

A Proofs

Proof. Proposition II.1

The Lagrangian associated to this program is the following:

$$\begin{aligned} \mathcal{L}_t = & u(-\theta_t - k_{t+1} + f(k_t) + (1 - \delta)k_t + (1 + r_{t-1})\theta_{t-1}) + \beta V_{t+1}(k_{t+1}, \theta_t) \\ & + \mu_t(\theta_t + \kappa k_{t+1}) \end{aligned}$$

The first-order conditions give us immediately

$$\begin{cases} \frac{\partial \mathcal{L}_t}{\partial \theta_t} = -u'(c_t) + \beta \frac{\partial V_{t+1}}{\partial \theta_t} + \mu_t \\ \frac{\partial \mathcal{L}_t}{\partial k_{t+1}} = -u'(c_t) + \beta \frac{\partial V_{t+1}}{\partial k_{t+1}} + \kappa \mu_t \end{cases}$$

Applying the envelope theorem,

$$\begin{cases} \frac{\partial V_{t+1}}{\partial \theta_t} = (1 + r_t) u'(c_{t+1}) \\ \frac{\partial V_{t+1}}{\partial k_{t+1}} = (1 - \delta + f'(k_{t+1})) u'(c_{t+1}) \end{cases}$$

In conclusion, when the credit constraint does not bind,

$$\begin{cases} f'(k_{t+1}) = r_t + \delta \\ u'(c_t) = \beta(1 + r_t) u'(c_{t+1}) \end{cases}$$

When the credit constraint binds,

$$\begin{cases} \theta_t \geq -\kappa k_{t+1} \\ u'(c_t) = \beta(1 + r_t^*) u'(c_{t+1}) \end{cases}$$

where $r_t^* = r_t + \frac{f'(k_{t+1}) - \delta - r_t}{1 - \kappa}$. □

Proof. Proposition II.2 The steady state is a fixed point for the distribution of (w^i, k^i, r) in the economy. Let us consider that a certain allocation is a fixed point. Assume that the mass of constrained agents is not equal to 0. This hypothesis translates into the following observation. As the consumption distribution should be a fixed point, this imposes that the mean of $\gamma \ln(\beta(1 + r_t^*))$ should be zero. As $r^* > r$ for unconstrained agents, it imposes first that $(1 + r_\infty)\beta < 1$. Unconstrained agents will over-consume immediately. Accordingly, from one period to the other, consumption of some constrained agents will individually increase; consumption of all unconstrained agents will individually decrease and their wealth will follow the same pattern. This imposes that the richest agents who see their wealth decrease should be replaced by poorer agents who see their wealth increase for the distribution of wealth to be fixed. As all unconstrained agents see their wealth decrease, this is

only possible if some constrained agents become the richest from one period to the other.

Consequently, going back to our initial hypothesis, no constrained agents can exist at the steady state.

If the steady state distribution can not allow for constrained agents, then the Euler equation brings immediately $\int_i c_\infty^i di - \int_i c_\infty^i di = \gamma \ln(\beta(1+r_\infty)) = 0$ which translates into $\beta(1+r_\infty) = 1$. This imposes that not only the distribution of consumption but also each individual consumption is fixed. In addition, the level of capital is not only fixed but equal across agents $k_\infty^i = f'^{-1}(r_\infty + \delta)$.

$$\begin{cases} r_\infty + \delta = f'(k_\infty) \\ \beta(1+r_\infty) = 1 \end{cases}$$

In the steady state, agents are homogeneous in terms of capital accumulation. \square

Proof. Lemma II.3

The proof will be organized as follows. First, I will determine the allocation of households once they have grown out of the credit constraints. Then, I will determine the dynamics for those constrained households during the first periods (while they are constrained) and find the condition under which the constraint binds.

Let us start then from the optimization of unconstrained households. Suppose that households inheriting k_t and θ_{t-1} are unconstrained under a fixed interest rate r_∞ . They will never be constrained in the future following the turnpike property established in complete markets. The level of capital that they accumulate will be $k_{t+1} = f'^{-1}(r_\infty + \delta) = k_\infty$. In addition, the evolution of consumption will follow the same pattern for everyone $c_t = c_{t+1} = c_\infty$. Consequently,

$$\begin{cases} c_\infty + k_\infty + \theta_t = (1-\delta)k_t + f(k_t) + (1+r_\infty)\theta_{t-1} \\ c_\infty + k_\infty + \theta_{t+1} = (1-\delta)k_\infty + f(k_\infty) + (1+r_\infty)\theta_t \\ \vdots \\ c_\infty + k_\infty + \theta_{t+\tau-1} = (1-\delta)k_\infty + f(k_\infty) + (1+r_\infty)\theta_{t+\tau-2} \\ c_\infty + k_\infty + \theta_{t+\tau} = (1-\delta)k_\infty + f(k_\infty) + (1+r_\infty)\theta_{t+\tau-1} \\ \vdots \end{cases}$$

Multiplying each row by $(1+r_\infty)^{-\tau}$ and summing over these equations,

$$\begin{aligned} \sum_{\tau=0}^{\infty} (1+r_\infty)^{-\tau} [c_\infty + k_\infty + \theta_{t+\tau}] &= \sum_{\tau=1}^{\infty} (1+r_\infty)^{-\tau} [(1-\delta)k_\infty + f(k_\infty) + (1+r_\infty)\theta_{t+\tau-1}] \\ &\quad + (1-\delta)k_t + f(k_t) + (1+r_\infty)\theta_{t-1} \end{aligned}$$

Under the assumption that $\lim_{\tau \rightarrow \infty} (1+r_\infty)^{-\tau} \theta_{t+\tau} = 0$,

$$\frac{1+r_\infty}{r_\infty} [c_\infty + k_\infty] = \frac{1}{r_\infty} [(1-\delta)k_\infty + f(k_\infty)] + (1-\delta)k_t + f(k_t) + (1+r_\infty)\theta_{t-1}$$

which becomes the intertemporal budget constraint:

$$c_\infty = w_\infty + \frac{r_\infty}{1+r_\infty}[(1-\delta)k_t + f(k_t)] + r_\infty\theta_{t-1}$$

where $w_\infty = \frac{f(k_\infty) - (r_\infty - \delta)k_\infty}{1+r_\infty}$. This last equation coupled with $k_{t+1} = f'^{-1}(r_\infty + \delta) = k_\infty$ fix the capital stock and consumption from t onwards.

The overall dynamics is composed of a first segment in which agents are constrained and try to grow as quickly as possible out of the credit frictions, and a second segment where consumption and capital stock are both fixed. The argument developed above allows us to capture the dynamics on the second segment. Solving the dynamics on the first segment is possible and necessitate a recursive process.

To this purpose, consider the first period for which agents become unconstrained $t = \tau + 1$. The consumption at this period can simply be written as:

$$c_{\tau+1} = c_0(w(k_{\tau+1})) = w_\infty + \frac{r_\infty}{1+r_\infty}w(k_{\tau+1})$$

where $w(x) = (1-\delta)x + f(x) - \kappa(1+r_\infty)x$ is the available revenue before we deduct future consumption as a function of capital in the constrained segment. Since, by definition, agents are constrained at $t = \tau$, $\kappa k_{\tau+1} + \theta_\tau = 0$ and the dynamic system can be written as:

$$\begin{cases} c_\tau + (1-\kappa)k_{\tau+1} = w(k_\tau) \\ c_\tau = c_{\tau+1} - \gamma \ln \left(1 + \frac{\beta}{1-\kappa} (f'(k_{\tau+1}) - f'(k_\infty)) \right) \end{cases}$$

Substituting c_τ in the first equation,

$$(1-\kappa)k_{\tau+1} + c_{\tau+1} - \gamma \ln \left(1 + \frac{\beta}{1-\kappa} (f'(k_{\tau+1}) - f'(k_\infty)) \right) = w(k_\tau)$$

Using the characterization of future consumption,

$$(1-\kappa)k_{\tau+1} + w_\infty + \frac{r_\infty}{1+r_\infty}w(k_{\tau+1}) - \gamma \ln \left(1 + \frac{\beta}{1-\kappa} (f'(k_{\tau+1}) - f'(k_\infty)) \right) = w(k_\tau) \quad (\text{Ro})$$

This equation determines then both $k_{\tau+1}$ and $c_\tau = w(k_\tau) - (1-\kappa)k_{\tau+1} = c_1(w(k_\tau))$ as a function of the inherited revenue $w(k_\tau)$ and indirectly the state variable k_τ . This process recursively defines $k_{\tau-(n+1)}$ as a function of $k_{\tau-n}$. Suppose that we have $c_{\tau-n} = c_n(w(k_{\tau-n}))$. At period $\tau - (n+1)$, agents are still constrained, they choose $k_{\tau-n}$ such that

$$(1-\kappa)k_{\tau-n} + c_n(w(k_{\tau-n})) - \gamma \ln \left(1 + \frac{\beta}{1-\kappa} (f'(k_{\tau-n}) - f'(k_\infty)) \right) = w(k_{\tau-(n+1)}) \quad (\text{Rn})$$

This equation defines both $k_{\tau-n}$ and $c_{\tau-n}$ as a function of $w(k_{\tau-(n+1)})$ and solves the problem backward.

The agent is constrained as long as the capital reachable with the previous equation is still lower than the optimal level k_∞ .

Since the term $\gamma \ln \left(1 + \frac{\beta}{1-\kappa}(f'(k_{t+1}) - f'(k_\infty))\right)$ is always positive except when the capital reaches its unconstrained level, the following inequality is a necessary and sufficient condition for being constrained.

$$w(k_t) - c_{t+1} < (1 - \kappa)k_\infty$$

□

Proof. Lemma II.5 The proof of this proposition is straightforward. Indeed, the second and third equations are just linear approximations at first order of the capital optimization and the Euler equation. The first equation is a linear approximation of the budget constraint of households where $\Theta_t = -\mu((1+r)\theta_{t-1} + \theta_t)$ is considered as given (it is, in particular, independent of the interest rate r_t). The actual program of the unaffected households is the following:

$$\begin{cases} c_t + k_{t+1} = (1 - \delta)k_t + f(k_t) + \Theta_t \\ k_{t+1} = f'^{-1}(r_t + \delta) \\ c_t = c_{t+1} - \gamma \ln(\beta(1 + r_t)) \end{cases}$$

As stated above, linearization at first-order gives us:

$$\begin{cases} \tilde{c}_t + \tilde{k}_{t+1} = (1 - \delta + f'(k_\infty)) \tilde{k}_t + \varepsilon_t \\ \tilde{k}_{t+1} = 1/f''(f^{-1}(r_\infty + \delta)) \tilde{r}_t \\ \tilde{c}_t = \tilde{c}_{t+1} - \gamma \tilde{r}_t \end{cases}$$

where \tilde{x} is the distance of variable x to its steady state value. Replacing $1 - \delta + f'(k_\infty) = (1 + r_\infty)$ and $\eta_\infty = -1/f''(f^{-1}(r_\infty + \delta))$ in the first and second equations above gives us the result. □

Proof. Proposition II.6 This proposition is a direct application of the two previous lemmas. Denote \bar{x} and \underline{x} respectively the variable x for initial winners - the happy lot - and initial losers - the unhappy few. Aggregate variables X can be written as $\mu\underline{x} + (1-\mu)\bar{x}$. Denote k the capital accumulation of affected agents which constitutes a separate process. Variables will be normalized around the steady state values.

The budget constraint in the economy can be written:

$$\tilde{C}_t + \tilde{K}_{t+1} = \left(1 - \delta + f'(k_\infty)\right) \tilde{K}_t + \mu \left[f(k_t) - f(k_\infty) - f'(k_\infty)(k_t - k_\infty) \right]$$

After a minor simplification,

$$\tilde{C}_t + \tilde{K}_{t+1} = (1 + r_\infty)\tilde{K}_t + \mu \left[f(k_t) - f(k_\infty) - f'(k_\infty)(k_t - k_\infty) \right]$$

The last term can be understood as the cost on the aggregate wealth of imperfections driving some agents away from the optimal path.

The aggregate capital at each period can be written as the sum of the two terms extracted from individual maximizations.

$$\tilde{K}_{t+1} = -\eta_\infty \tilde{r}_t + \mu [k_{t+1} - k_\infty]$$

Finally, the Euler equations give us:

$$\tilde{C}_t = \tilde{C}_{t+1} - \gamma \tilde{r}_t - \gamma \ln \left(1 + \frac{\beta}{1-\kappa} (f'(k_{t+1}) - f'(k_\infty)) \right)$$

Substituting \tilde{r}_t ,

$$\tilde{C}_t = \tilde{C}_{t+1} + \frac{\gamma}{\eta_\infty} \tilde{K}_{t+1} - \mu \left[\gamma \ln \left(1 + \frac{\beta}{1-\kappa} (f'(k_{t+1}) - f'(k_\infty)) \right) + \frac{\gamma}{\eta_\infty} (k_{t+1} - k_\infty) \right]$$

Overall, the dynamics is entirely determined by the following system:

$$\begin{cases} \tilde{C}_t + \tilde{K}_{t+1} = (1 + r_\infty) \tilde{K}_t + \mu [f(k_t) - f(k_\infty) - f'(k_\infty)(k_t - k_\infty)] \\ \tilde{C}_t = \tilde{C}_{t+1} + \frac{\gamma}{\eta_\infty} \tilde{K}_{t+1} - \mu \left[\gamma \ln \left(1 + \frac{\beta}{1-\kappa} (f'(k_{t+1}) - f'(k_\infty)) \right) + \frac{\gamma}{\eta_\infty} (k_{t+1} - k_\infty) \right] \end{cases}$$

Without any credit constraints, the error terms in both equations disappear and the dynamics is a representative-agent dynamics. \square

B Tables and figures

Figure F1: Separate evolutions of capital formation, financial system deposits after a catastrophe (confidence interval at 90%). Calibrated on two countries with: average financial development of 10% (left panel), average financial development of 90% (right panel).

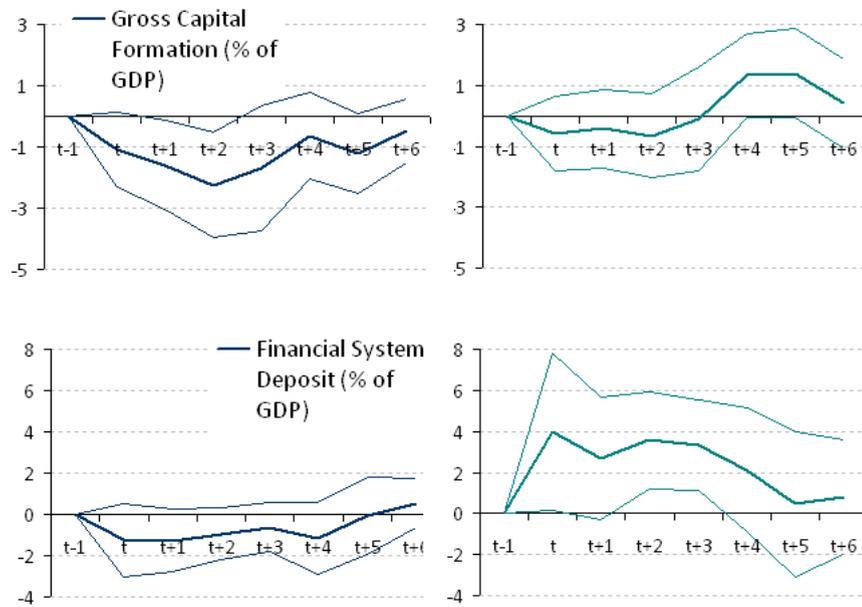


Figure F2: Comparing the subsample of affected countries to unaffected countries along GDP per capita.

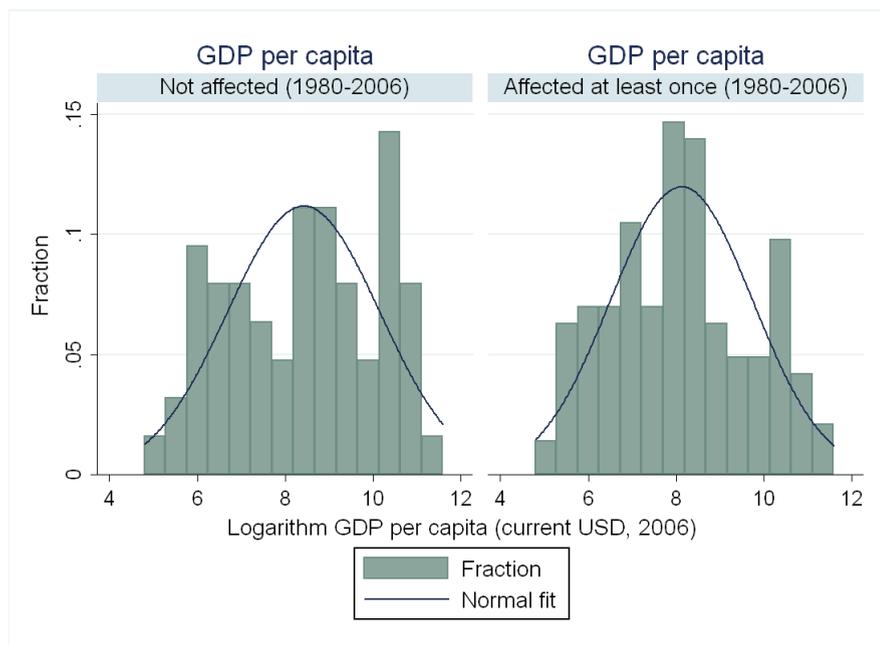


Figure F3: Comparing the subsample of affected countries to unaffected countries along financial development.

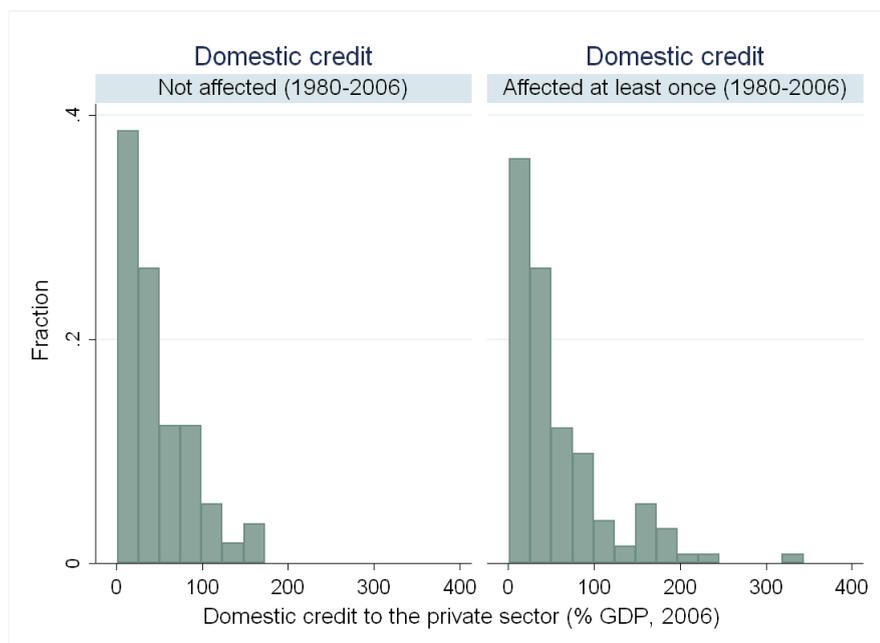


Table T1: Impact of natural disasters on the evolutions of capital formation, deposits and spread

	Gross fixed cap. form.	Gross cap. form.	Bank deposits	Fin. deposits	Spread rate
Specifications	AB	AB	AB	AB	AB
Shock (t)	-1.19 (.521)*	-1.15 (.826)	-1.95 (1.43)	-1.88 (1.48)	22.3 (19.9)
Shock ($t - 1$)	-2.06 (.756)**	-1.75 (.975) [†]	-1.64 (1.18) [†]	-1.76 (1.23)	84.2 (45.6) [†]
Shock ($t - 2$)	-2.42 (.848)**	-2.46 (.114)*	-1.38 (.965)	-1.52 (.990)	127 (59.0)*
Shock ($t - 3$)	-1.85 (.986)	-1.89 (1.34)	-1.01 (.925)	-1.12 (.948)	117 (58.0)*
Shock ($t - 4$)	-1.36 (.975)	-.877 (.975)	-1.43 (1.27)	-1.55 (1.33)	98.5 (59.8) [†]
Shock ($t - 5$)	-.671 (.742)	-1.15 (.945)	-.039 (1.42)	-.148 (1.47)	19.1 (56.8)
Shock ($t - 6$)	-.797 (.717)	-.567 (.765)	.634 (.983)	-34.0 (1.01)	(41.6)
Shock \times FD (t)	.013 (.009)	.006 (.012)	.006 (.004) [†]	.007 (.004)	-.055 (.047)
Shock \times FD ($t - 1$)	.023 (.011)*	.015 (.013)	.005 (.003)	.005 (.003)	-.171 (.103) [†]
Shock \times FD ($t - 2$)	.025 (.015) [†]	.020 (.014)	.005 (.003)*	.006 (.003)*	-.241 (.141) [†]
Shock \times FD ($t - 3$)	.016 (.012)	.020 (.015)	.005 (.002)*	.005 (.002)*	-.218 (.138)
Shock \times FD ($t - 4$)	.017 (.016)	.025 (.015) [†]	.004 (.003)	.004 (.003)	-.191 (.146)
Shock \times FD ($t - 5$)	.019 (.015)	.033 (.017) [†]	.000 (.004)	.001 (.004)	-.034 (.144)
Shock \times FD ($t - 6$)	.007 (.013)	.010 (.016)	.000 (.003)	.000 (.003)	.084 (.096)
Additional controls	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes
Test for AR(1) ($\text{Pr} > z$)	.012	.005	.000	.000	.237
Test for AR(2) ($\text{Pr} > z$)	.183	.281	.010	.009	.992
Observations	2346	2430	1826	1826	1549

Significantly different than zero at [†] 90% confidence, * 95% confidence, ** 99% confidence. (AB) is a specification using Arellano-Bond System GMM estimator with 2-periods lags. The dependent variable are the gross capital formation, the gross fixed capital formation for the ongoing year as a share of GDP, the bank and financial system deposits as a share of GDP, and the spread rate (lending rate minus deposit rate). The exposure is the annual exposed population to earthquakes or wind-based events (of category 1) divided by the population. FD stands for financial development, captured by the percentage of domestic credit over GDP averaged over the period 1980-2006. The attrition is explained by the lack of reliable data on financial indicators for almost 1/3 of the countries.

Table T2: Robustness checks for immediate output with different measures of exposure

Role of credit on indirect losses - robustness checks						
Specifications	GDP growth t					
	OLS	AB	OLS	AB	OLS	AB
Shock \times FD	.031	.025				
(cat. 0)	(.015)*	(.010)*				
Shock	-1.92	-1.44				
(cat. 0)	(.72)**	(.43)**				
Shock \times FD			.045	.026		
(cat. 2)			(.020)*	(.014)*		
Shock			-3.59	-1.77		
(cat. 2)			(1.0)**	(.69) [†]		
Shock \times FD					.008	-.001
(sum)					(.006)	(.006)
Shock					-.481	-.105
(sum)					(.25) [†]	(.22)
Propensity \times FD	-.002		-.000		-.001	
	(.002)		(.001)		(.001)	
Propensity	.048		.017		.014	
	(.095)		(.091)		(.091)	
GDP growth ($t - 1$)	.272	.134	.272	.133	.273	.132
	(.05)**	(.05)**	(.05)**	(.05)**	(.05)**	(.05)**
Additional controls	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects		Yes		Yes		Yes
Country fixed effects		Yes		Yes		Yes
Observations	2797	2957	2797	2957	2797	2957

Significantly different than zero at [†] 90% confidence, * 95% confidence, ** 99% confidence. (AB) is a specification using Arellano-Bond System GMM estimator with 2-periods lags. The dependent variable is the GDP growth for the ongoing year. The exposure is the annual exposed population to earthquakes or wind-based events (of category 0 and 2) divided by the population and the sum of energy weighted by the local density. Propensities are computed as the percentage of the population in risky zones at each date. The set of additional controls include gross capital formation, current account, reserves, government expenditures, credit and exports at $t - 1$. FD stands for financial development, captured by the percentage of domestic credit over GDP averaged over the period 1980-2006.

Table T3: Impact of different thresholds for natural disasters on immediate output

Indirect losses - robustness checks							
Specifications	GDP growth t						
	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Shock (cat. 0)	-.994 (.414)*						
Shock (cat. 1)		-1.17 (.433)**					
Shock (cat. 2)			-1.91 (.466)**				
Shock (cat. 3)				-2.00 (.475)**			
Shock (cat. 4)					-4.49 (1.21)**		
Shock (cat. 5)						-14.2 (7.30)*	
Shock (sum)							-.204 (.085)*
Additional controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2797	2797	2797	2797	2797	2797	2797

Significantly different than zero at [†] 90% confidence, * 95% confidence, ** 99% confidence. The results are shown omitting the coefficients for the control variables (growth, GDP per capita, current account, government consumption, credit, reserves, capital formation, imports and FDI inflows at $t - 1$) and propensities to be affected. The exposure is the annual exposed population to earthquakes or wind-based events (of category 1, 2, 3, 4 and 5) divided by the population and the sum of energy weighted by the local density (sum).

Table T4: Underlying parameters extracted from the structural model

Structural parameter χ_e^i					
Country (ISO)	Value	Country (ISO)	Value	Country (ISO)	Value
ECU	-0.27	DMA	0.13	MOZ	0.21
COL	-0.13	ATG	0.14	JAM	0.22
NZL	-0.04	AZE	0.15	CHL	0.22
NIC	-0.02	ROU	0.15	VCT	0.23
USA	-0.01	GRC	0.16	VNM	0.26
ABW	0	COM	0.16	PER	0.27
DJI	0	HKG	0.17	LAO	0.3
ISL	0.01	BRB	0.17	EGY	0.34
CYP	0.03	VUT	0.18	TUR	0.38
BEN	0.03	TON	0.18	SWZ	0.43
SLB	0.03	GTM	0.18	ALB	0.44
NPL	0.04	MWI	0.18	AND	0.46
BLZ	0.05	MUS	0.18	FJI	0.46
IRL	0.05	MDG	0.18	KGZ	0.47
DOM	0.06	PRI	0.19	TTO	0.48
KOR	0.09	BHS	0.19	PNG	0.51
CAN	0.11	SLV	0.2	MDA	0.66
MEX	0.11	KNA	0.2	CPV	0.81
GRD	0.11	DZA	0.2	BTN	0.97
PHL	0.12	CRI	0.21	PAN	1.22
HND	0.13	TJK	0.21		
LCA	0.13	JPN	0.21		

These values have been computed using the evolution of gross fixed capital formation as a proxy for investment. Note that some of these coefficients are negative. Remember that they represent the area between the frictionless case and the actual evolution. A negative area could be explained by an even faster recovery than predicted by the frictionless case.

Figure F4: Overview of the population density in 2005 and cyclone risk since 1980.

