A theory of disasters and long-run growth

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Plan of talk

Background

Economic impacts of disasters

- Growing empirical literature
- Conflicting evidence:
  - Negative impact on growth (Raddatz, 2007; Noy, 2009; Hsiang and Jina, 2014, 2015)
  - Rather positive influence on long-term growth (Skidmore & Toya, 2002)
- When and how do disasters facilitate growth?

Observed facts

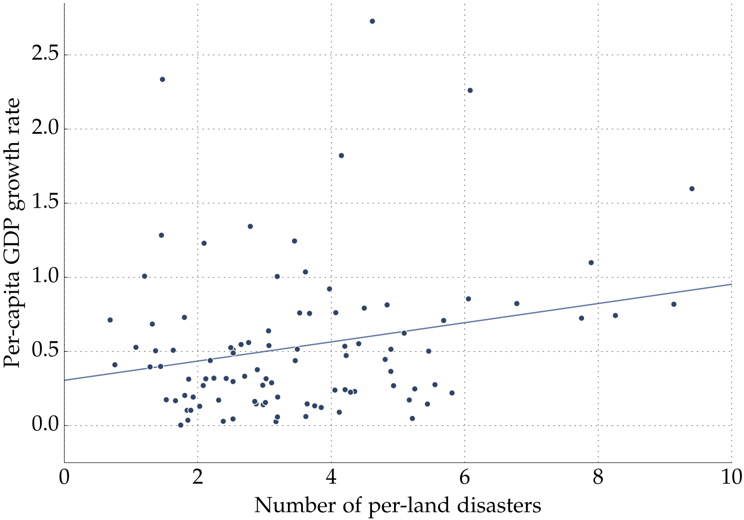
- Frequency of some types of disasters is positively correlated with long-term economic growth
- Human capital accumulation and productivity growth are both facilitated

Disaster frequency (1960–2012)

	total	by type
United States	770	Storm (484), Flood (148), Wildfire (60)
China	664	Storm (216), Flood (206), Earthquake (121)
India	560	Flood (234), Storm (137), Epidemic (63)
Philippines	521	Storm (283), Flood (131), Landslide (30)
Indonesia	405	Flood (151), Earthquake (99), Volcanic (46)
Bangladesh	299	Storm (148), Flood (85), Epidemic (29)
Japan	228	Storm (116), Earthquake (40), Flood (35)
Mexico	216	Storm (82), Flood (57), Earthquake (27)
Australia	209	Storm (98), Flood (59), Wildfire (28)
Russia	198	Flood (69), Earthquake (28), Storm (24)
Brazil	197	Flood (114), Landslide (21), Drought (17)
Viet Nam	179	Storm (88), Flood (68), Epidemic (10)
Iran	178	Earthquake (90), Flood (66), Storm (12)

Source: EM-DAT, the OFDA/CRED International Disaster Database

Positive correlation (1960–2012)



But why?

Suggested explanations

- Investment return tilted in favor of human capital
  $\leftarrow$ biased damage against physical capital
- Or perhaps technology upgrading facilitated

$\rightarrow$ Are disasters a blessing in disguise?

Formal analysis is missing

- To further investigate the mechanism and implications, theoretical framework is required
- In the literature of long-term economic growth, however, little attention paid to disasters
- Need to fill this gap by augmenting the standard framework of economic growth

Our approach

General framework

- Introducing disasters to the canonical discrete-time infinite-horizon optimization problem
- Basic existence results established in a general form
- This is done by reformulating the stochastic problem into an ‘equivalent’ deterministic problem

Application

- Applied to a two-sector endogenous growth example à la Lucas (1988)
- Long-run equilibrium as well as transition phase fully characterized
- Formal link between disasters and economic growth established in a transparent way

Modeling disasters

Aggregate risk

- Some disasters catch us by surprise (ex. earthquake)
- Modeled as:
  - destroying all kinds of capital at once
  - stochastic event
- Capture the unpredictability of disaster

Idiosyncratic risk

- Small-scale yet more frequent (ex. storms, droughts)
- Modeled as:
  - destroying specific kind of capital
  - non-stochastic event
- Capture the biased damage against specific capital

Findings: a preview

Biased damage

- Biased damage against inefficiently accumulated physical capital could improve the long-run growth rate
- Even in the efficient path, physically destructive disasters can boost the growth of economy in transition

→ What matters is technology

Unpredictability

- Unpredictable nature of disaster matters
- Prospect of consumption drop in the future may facilitate savings (and suppress consumption) today
- Welfare implications of the apparently positive impacts of disaster should be interpreted with some care

→ Crucial here is rather preference

General framework

Model setup

- Technology is represented by a general transition correspondence $\Gamma : \mathbb{R}^n_+ \rightrightarrows \mathbb{R}^n_+$
- Preference is captured by per-period return function $R : \mathbb{R}^n_+ \times \mathbb{R}^n_+ \to \mathbb{R}$ together with discount factor $\beta \in (0, 1)$

Canonical problem w/o disasters

- Dynamic optimization problem is then

$$V(\boldsymbol{x}) := \sup_{\{\boldsymbol{x}_t\}_{t=1}^{\infty}} \sum_{t=0}^{\infty} \beta^t R(\boldsymbol{x}_t, \boldsymbol{x}_{t+1}) \qquad \text{(CP)}$$
$$\text{s.t.} \quad \boldsymbol{x}_{t+1} \in \Gamma(\boldsymbol{x}_t), \;\; \boldsymbol{x}_0 = \boldsymbol{x}$$

- This type of problem is well understood in the literature
- Alvarez & Stokey (1998), Le Van & Morhaim (2002)

Introducing aggregate risk

Aggregate risk of disasters

- Unpredictable disaster at the beginning of each period
- Bernoulli process with probability $\lambda \in (0, 1)$
- Fraction $\alpha \in (0, 1)$ of capital stocks survive
- Denote by $D^t := (D_1, \ldots, D_t) \in \times_{i=1}^{t} \{1, \alpha\}$ the history of disasters up until period t

Stochastic optimization problem

- Problem is then

$$V(\boldsymbol{x}) := \sup_{\{\boldsymbol{x}_t\}_{t=1}^{\infty}} \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t R(D_t \boldsymbol{x}_t(D^{t-1}), \boldsymbol{x}_{t+1}(D^t))\right] \qquad \text{(SP)}$$

$$\text{s.t.} \quad \boldsymbol{x}_{t+1}(D^t) \in \Gamma(D_t \boldsymbol{x}_t(D^{t-1})), \;\; \boldsymbol{x}_0(D^{-1}) = \boldsymbol{x}$$

- How is the solution of (SP) affected by disasters?

Reformulating the problem

Assumptions

- Graph of Γ is a cone
- R is homogeneous of degree $\theta < 1$

$\rightarrow$ Consistent with many economic models

Lemma 2.1. Value function equivalence

- Under the assumptions above, $V(\boldsymbol{x})$ in (SP) satisfies

$$V(\boldsymbol{x}) = \sup_{\{\tilde{\boldsymbol{y}}_t\}_{t=1}^{\infty}} \sum_{t=0}^{\infty} \tilde{\beta}^t R(\tilde{\boldsymbol{y}}_t, \tilde{\boldsymbol{y}}_{t+1}) \quad \text{s.t.} \quad \tilde{\boldsymbol{y}}_{t+1} \in \Gamma(\tilde{\boldsymbol{y}}_t), \;\; \tilde{\boldsymbol{y}}_0 = \boldsymbol{x} \tag{DP}$$

for each $\boldsymbol{x}$, where

$$\tilde{\beta} := (\lambda\alpha^{\theta} + 1 - \lambda)\beta \tag{1}$$

- Observe the connection to the result of Yaari (1965)

What about the policy function?

Standing on the shoulder of giants

- Problem is now given in a familiar deterministic form
- We can apply the powerful tools already established in the deterministic optimization theory
- Assume that a couple of commonly-used technical conditions are all satisfied (Le Van, 2006)

Proposition 2.1. Policy function equivalence

- Then there exists an optimal policy function $\psi : \mathbb{R}^n_+ \to \mathbb{R}^n_+$ to the deterministic problem (DP)
- Moreover, this ψ is also an optimal policy function to the original stochastic problem (SP)

$\to$ Focusing on (DP) hence proves to be sufficient for the characterization of the solution of (SP)

Capturing biased damage

Small-scale biased disasters

- Assuming that the risk is idiosyncratic, the aggregate impact may be modeled as a deterministic process:
  - end-of-t capital: $(\tilde{y}_{1,t}, \tilde{y}_{2,t}, \ldots, \tilde{y}_{n,t}) =: \tilde{\boldsymbol{y}}_t$
  - $t+1$ capital: $(\zeta_1\tilde{y}_{1,t}, \zeta_2\tilde{y}_{2,t}, \ldots, \zeta_n\tilde{y}_{n,t}) =: \boldsymbol{\zeta}\tilde{\boldsymbol{y}}_t$

Combining aggregate and idiosyncratic risks

- Optimization problem is now given by

$$V(\boldsymbol{x}) = \sup_{\{\tilde{\boldsymbol{y}}_t\}_{t=1}^{\infty}} \sum_{t=0}^{\infty} \tilde{\beta}^t \tilde{R}(\tilde{\boldsymbol{y}}_t, \tilde{\boldsymbol{y}}_{t+1}) \tag{P}$$

$$\text{s.t.} \quad \tilde{\boldsymbol{y}}_{t+1} \in \tilde{\Gamma}(\tilde{\boldsymbol{y}}_t), \;\; \tilde{\boldsymbol{y}}_0 = \boldsymbol{\zeta}^{-1}\boldsymbol{x},$$

where

$$\tilde{R}(\tilde{\boldsymbol{y}}, \tilde{\boldsymbol{y}}') := R(\boldsymbol{\zeta}\tilde{\boldsymbol{y}}, \tilde{\boldsymbol{y}}'), \quad \tilde{\Gamma}(\tilde{\boldsymbol{y}}) := \Gamma(\boldsymbol{\zeta}\tilde{\boldsymbol{y}}) \tag{2}$$

Application: Lucas (1988) model

Basic setup

- Now we specify $\boldsymbol{y}_t = (K_t, H_t) \in \mathbb{R}^2_+$, where
  - K_t is physical capital, and
  - H_t is human capital, both at the end of period t
- Allocating raw labor (normalized to unity):
  - $Y_t = F(K_{t-1}, (1 - n_t)H_{t-1})$
  - $H_t = G(n_t H_{t-1})$

Capital accumulation

- Full capital depreciation assumed:

$$K_t = Y_t - C_t \tag{3}$$

- In the associated continuous-time model, this assumption can be easily dropped

Preference and technology

Preference

- One-period utility function specified as

$$u(C) := \begin{cases} C^\theta/\theta & \text{for } \theta \in (-\infty, 1) \setminus \{0\} \\ \ln(C) & \text{for } \theta = 0 \end{cases} \tag{4}$$

- Assuming logarithmic utility (i.e., $\theta = 0$) misses out on important insights, as we will see later
- $1/(1-\theta)$ is the elasticity of intertemporal substitution

Technology

- Functional G is linear
- Functional form of F not specified (yet)
- Smoothness, concavity, linear homogeneity assumed
- Inada condition

Problem

Stochastic growth model

- We consider the problem

$$\max_{\{C_t,n_t\}_{t=1}^{\infty}} \mathbb{E}\left[\sum_{t=1}^{\infty}\beta^{t-1}u(C_t)\right] \tag{SP'}$$

$$\begin{aligned} \text{s.t.}\quad & K_t = F\left(D_t\zeta_K K_{t-1}, D_t\zeta_H H_{t-1}\left(1-n_t\right)\right) - C_t \geq 0, \\ & H_t = n_t D_t \eta \zeta_H H_{t-1} \geq 0, \\ & C_t \geq 0, 1 \geq n_t \geq 0 \end{aligned}$$

- (SP') may be written as (SP) once we define

$$\tilde{R}(K,H,K',H') := u(F(\zeta_K K, \zeta_H H - \eta^{-1}H') - K'),$$

$$\begin{aligned} \tilde{\Gamma}(K,H) := \{(K',H') \in \mathbb{R}_+^2 \mid F(\zeta_K K, \zeta_H H - \eta^{-1}h) \geq K', \\ \zeta_H H \geq \eta^{-1}H'\} \end{aligned} \tag{5}$$

Solution

Proposition 2.2. Policy function equivalence

- Assumptions for Prop. 2.1 all satisfied as long as

$$(\zeta_H \eta)^\theta (\lambda \alpha^\theta + 1 - \lambda)\beta < 1 \qquad (*)$$

- Policy function of (SP') may then be obtained by solving

$$\max_{\{(\tilde{K}_t, \tilde{H}_t)\}_{t=1}^\infty} \sum_{t=1}^\infty \tilde{\beta}^{t-1} \tilde{R}(\tilde{K}_{t-1}, \tilde{H}_{t-1}, \tilde{K}_t, \tilde{H}_t) \qquad \text{(DP')}$$

$$\text{s.t.} \qquad (\tilde{K}_t, \tilde{H}_t) \in \tilde{\Gamma}(\tilde{K}_{t-1}, \tilde{H}_{t-1})$$

Characterization

- Characterize the solution of (SP') based on (DP')
- First focusing on the balanced growth path
- And then on the transition phase

Balanced growth path

Proposition 3.2. Existence & uniqueness of BGP

- Unique BGP exists iff $(*)$ is satisfied
- Balanced growth rate is given by

$$\tilde{g}^* := (\beta[\lambda\alpha^\theta + (1-\lambda)]\eta\zeta_H)^{\frac{1}{1-\theta}}, \tag{6}$$

  which is a function of disaster-related parameters!

Proposition 3.3. Disaster and long-run growth

- Long-run growth rate is:
  - lowered by human-targeted periodic disasters, but not affected by physically destructive disasters,
  - negatively affected by aggregate risk if $\theta > 0$, but the impact is rather positive when $\theta < 0$.
- Aggregate risk plays no role if $\theta = 0$ (logarithmic)

Implication: biased damage

Human-targeted disasters

- Affect the productivity in human capital sector — the growth engine — and thus reduce the growth rate
- In a country where human-related resources are vulnerable to disasters, its long-run growth rate should be smaller

Physically destructive disasters

- Neutral effect when the resource allocation is efficient
- Indicating disasters of this type can boost the growth rate if physical capital is inefficiently overaccumulated, as suggested by Skidmore & Toya (2002)
- Welfare-improving channel through which disasters and growth can be positively correlated

Implication: unpredictability

Mixed results

- Two distinct motives:
  - Savings facilitated in anticipation of sudden declines in future consumption
  - Consumption encouraged because savings would put the resources at risk
- One motive dominates the other, depending on θ

Growth may be driven by disasters, but at a cost

- $\theta < 0$ implies (low elasticity, thus) precautionary savings
- Disaster-growth correlation then emerges
- Only possible at the cost of suppressed consumption

$\rightarrow$ If this is the case, welfare impact of disaster-driven economic growth is negative

Stability of BGP

Additional assumption

- Characterize the economy off the BGP
- To this end, we now specify F as

$$F(K,L) := \left(\nu K^{\frac{\sigma-1}{\sigma}} + (1-\nu)L^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{7}$$

for some $\nu \in (0,1)$ and $\sigma \in (0,\infty)\setminus\{1\}$

Proposition 3.4. Stability and monotonicity

- Optimal path of consumption growth rates monotonically converges to the balanced growth rate
- Convergence itself is not affected by any occurrence of aggregate disasters
- Hence, our analysis of BGP in the deterministic formulation is relevant

Transition dynamics

Proposition 3.5. Speed of convergence

- Compare two distinct economies such that
  - their long-run growth rates are identical
  - but the magnitudes of disasters are different
- Economy with a larger magnitude of physically destructive disasters converges faster iff $\sigma > 1$
- Yet another channel for positive correlation (but again with negative welfare consequence)

Technological substitutability matters

- Investment shifts from physical to human capital
- Production not affected much if K and L are substitutes
- Human capital then bumps up the growth rate

$\rightarrow$ Not the case if the two inputs are complements

Conclusions

Findings and policy implications

- Various possible channels behind the observed data:
  1. Inefficiency removal by biased damage
  2. Human capital accumulation facilitated by biased damage
  3. Precautionary saving against unpredictable disasters
- Except for the first case, people better off by disaster prevention even though growth rate declines

For future empirical study

- Which channel is at work?
- Maybe multiple channels simultaneously at work
- Identifying the dominating channel would be an issue