Disasters and Defaults

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Rising climate-related disaster risk

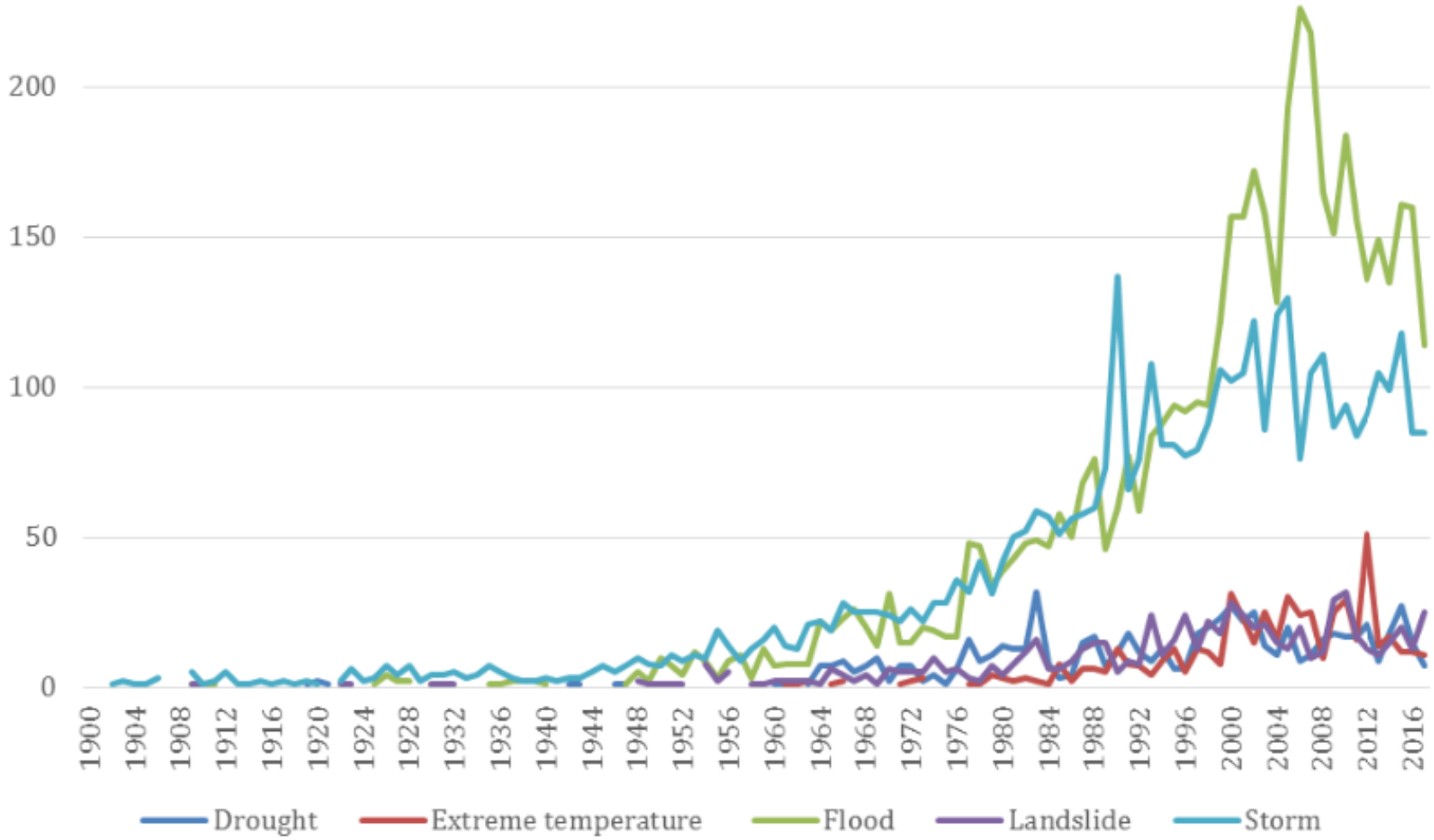


Figure: Number of climate-related catastrophes 1900-2017

Source: EM-DAT, compiled by Kling et al 2018.

Lasting disaster damages

A case study: Hurricane Maria

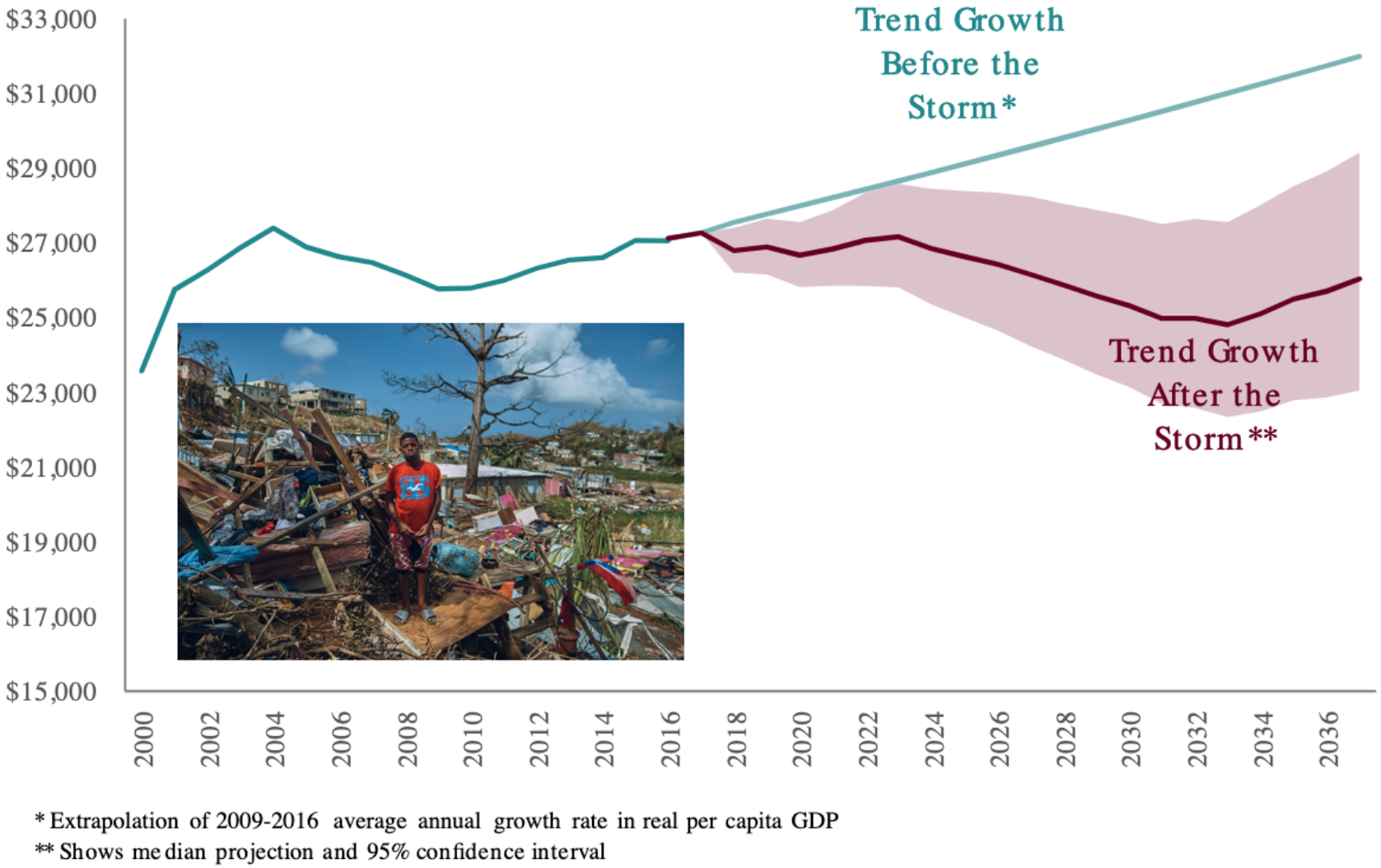


Figure: Puerto Rico GDP/capita

Lasting disaster damages

General patterns

- Large cyclones hurt GDP *trends* (Hsiang Narita 2014)
  - 90th percentile cyclone (5.8% annual prob)'s effect on income $\approx$ that from banking crisis
  - Effects are persistent (up to 2 decades)
  - Damages are more severe in EMs with less financial development (Bakkensen Barrage 2019)
- *Climate risks affect sovereign risks* in EMs
  - 90th percentile storm raises Pr(debt crisis) by 4pp (Klomp 2017)
    - ★ Case study: Hurricane Ivan 2004 & subsequent default by Grenada (Asonuma et al 2018)
  - Ex-post effect: Climate-related disasters persistently increase spreads (Klomp 2015)
  - Ex-ante effect: Countries vulnerable to climate risks face higher bond yields (Beirne et al 2020, Kling et al 2018)

This paper

- Model to characterize effects of disaster risk on sovereign default risk
  - Map to empirical patterns
- Welfare analysis of disaster policies:
  - Debt relief policies (nontrivial ex-ante & ex-post tradeoffs, forgiveness Laffer curve)
  - Catastrophe bonds
  - Significant welfare gain, driven by reduced default risk
  - Implication: Explicit modeling of strategic default is critical for analysis of disaster-contingent policies

Related literature

- **Sovereign default models:** Eaton Gersovitz (1981), Grossman Van Huyck (1988), Bulow Rogoff (1989), Aguiar Gopinath (2006), Arellano (2008), Aguiar Chatterjee Cole Stangebye (2016), Adam Grill (2017), Arellano et al (2020), [and many more from workshop participants]...
- **Rare disaster models:** Rietz (1988), Barro (2006), Gabaix (2011), Gourio (2012), Bansal Kiku Ochoa (2019), ...
- (Disaster-) contingent bonds: Braun Todd Wallace (1999), Borensztein Cavallo Jeanne (2017), Borensztein Mauro (2004)
- **Closest:** *Rebelo Wang Yang (2019) & Mallucci (2020)*
  - We focus on welfare implications of disaster policies

Model

$$
\begin{aligned}
U &= E_0 \sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\gamma}}{1-\gamma} \\
\ln \frac{Y_t}{Y_{t-1}} &= \underbrace{g_t}_{\text{Markov growth shock}} - \underbrace{x_t}_{\text{disaster dummy}} \underbrace{d}_{\text{growth damage}} \\
\Pr(x' = 1|x) &= p_x, \\
p_1 &\geq p_0 \geq 0 \\
d &\geq 0 \\
1 &> \beta(1+r) E_{g,x} \left[(1-p_x) e^{(1-\gamma)g} + p_x e^{(1-\gamma)(g-d)} \right]
\end{aligned}
$$

Detrended value functions ($b := \frac{B}{Y}, b^n := \frac{B'}{Y}$)

$$v(b, \underbrace{g, x}_{s}) = \max\left\{v^R(b,s), v^D(s)\right\}$$

$$v^R(b,s) = \max_{b^n} \frac{(1-b+q(b^n,s)b^n)^{1-\gamma}}{1-\gamma} + \beta E_s\left[v(e^{x'd-g'}b^n, s')e^{(1-\gamma)(g'-x'd)}\right]$$

$$q(b^n,s) = \frac{\Pr_s\left[v^R(e^{x'd-g'}b^n, s') \geq v^D(s')\right]}{1+r}$$

$$v^D(s) = \frac{(1-\ell)^{1-\gamma}}{1-\gamma} + \beta E_s\left[\left\{(1-\pi_{exit})v^D(s') + \pi_{exit}v^R(0,s')\right\}e^{(1-\gamma)(g'-x'd)}\right]$$

Increasing disaster frequency/intensity reduces debt price

Proposition 1

Assume $\pi_{exit} = 0$.

$$\frac{\partial q}{\partial p_x}, \frac{\partial q}{\partial d} \leq 0$$

- Implication: EMs more vulnerable to climate risks face higher bond yields & prob of debt crises
- Evidence: Beirne et al (2020), Kling et al (2018)

Disaster reduces debt price

Proposition 2

Assume $\pi_{exit} = 0$.

$$q(b^n, 1) \leq q(b^n, 0) \quad \forall b^n$$

- Implication: natural disasters raise spreads & likelihood of default in EMs
- Evidence: Klomp (2015, 2017)

Disaster Policy Analysis:

Debt Relief & CAT bonds

Motivation

- Bolton et al (2020): "International law **doctrine of 'necessity'** (...) applies in the **narrow set of circumstances** where nations – through no fault of their own – **need to compromise certain legal obligations** in order to divert resources to meet the urgent needs of their population."
- Richmond Dias (2009): existence of natural disaster before defaults reduces exclusion period, consistent with idea of **excusable default** (Grossman Van Hyuck 1988)

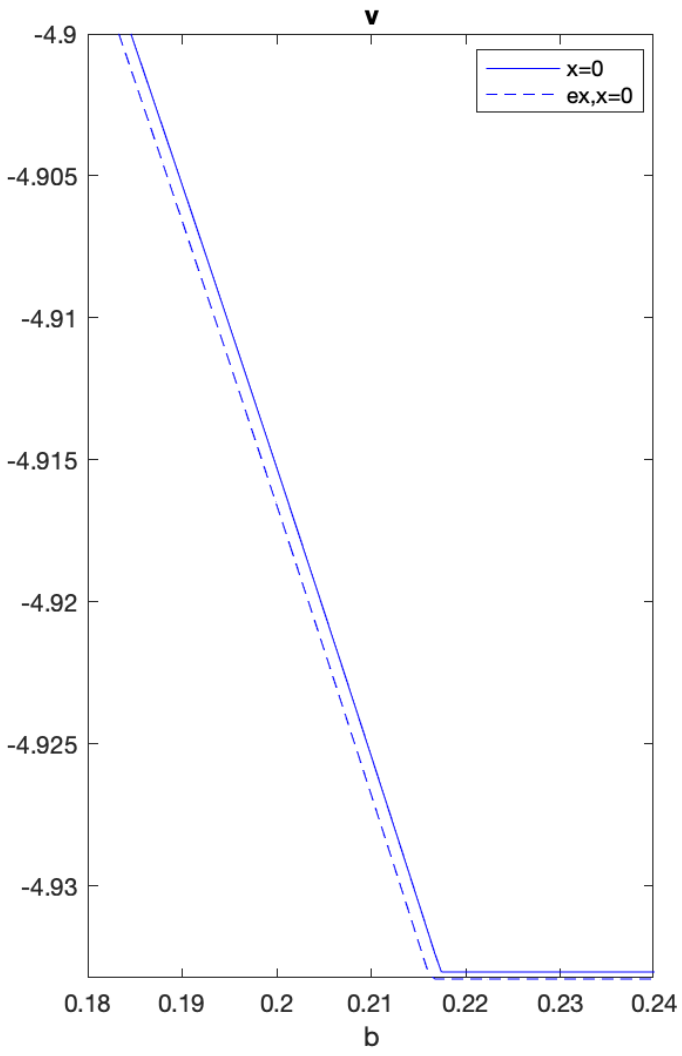
Experiment 0: Excusable default

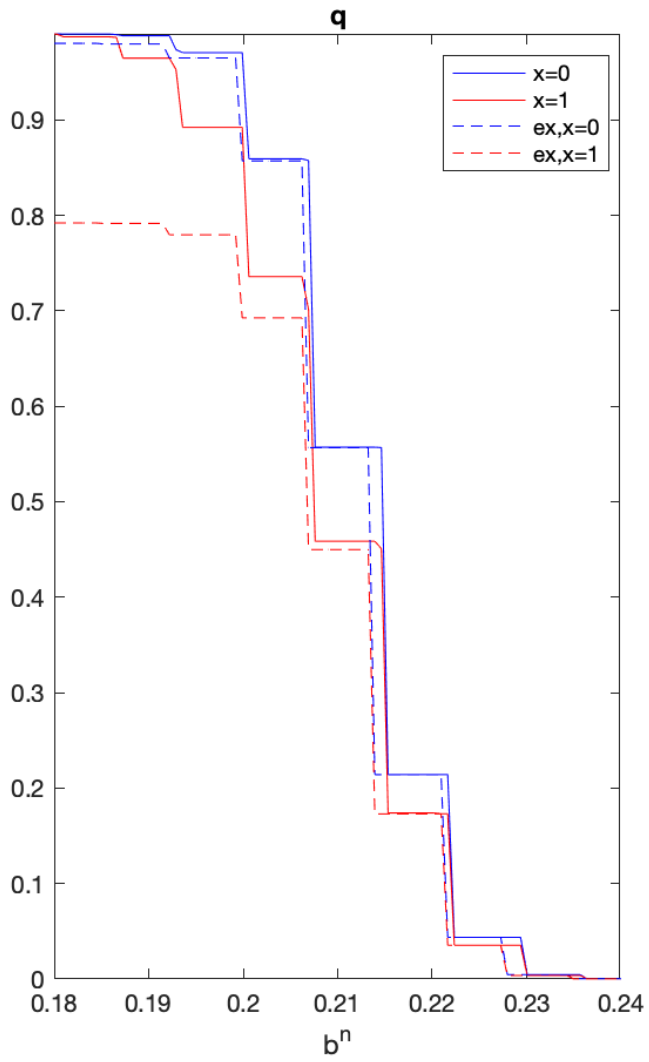
- Suppose default is excusable in disaster state
  - Equivalent to 100% of debt forgiven in disaster state

$$v_{ex}^{R}(b,s) = \max_{b^n} u(1-(1-x1_{b\geq 0})b + q_{ex}(b^n,s)b^n) + \beta E_s\left[v_{ex}(e^{x'd-g'}b^n,s')e^{(1-\gamma)(g'-x'd)}\right]$$

- Rational lenders price this excusable clause:

$$q_{ex}(b^n \geq 0, s) = \frac{1-p_x}{1+r}\Pr\left[\text{repay}(e^{-g'}b^n)|g,x'=0\right]$$





- Full forgiveness can actually *reduce* ex-ante welfare

Experiment 1: Simple debt relief

- Assume a fraction $\bar{\phi} \in [0,1]$ of debt is forgiven in disaster

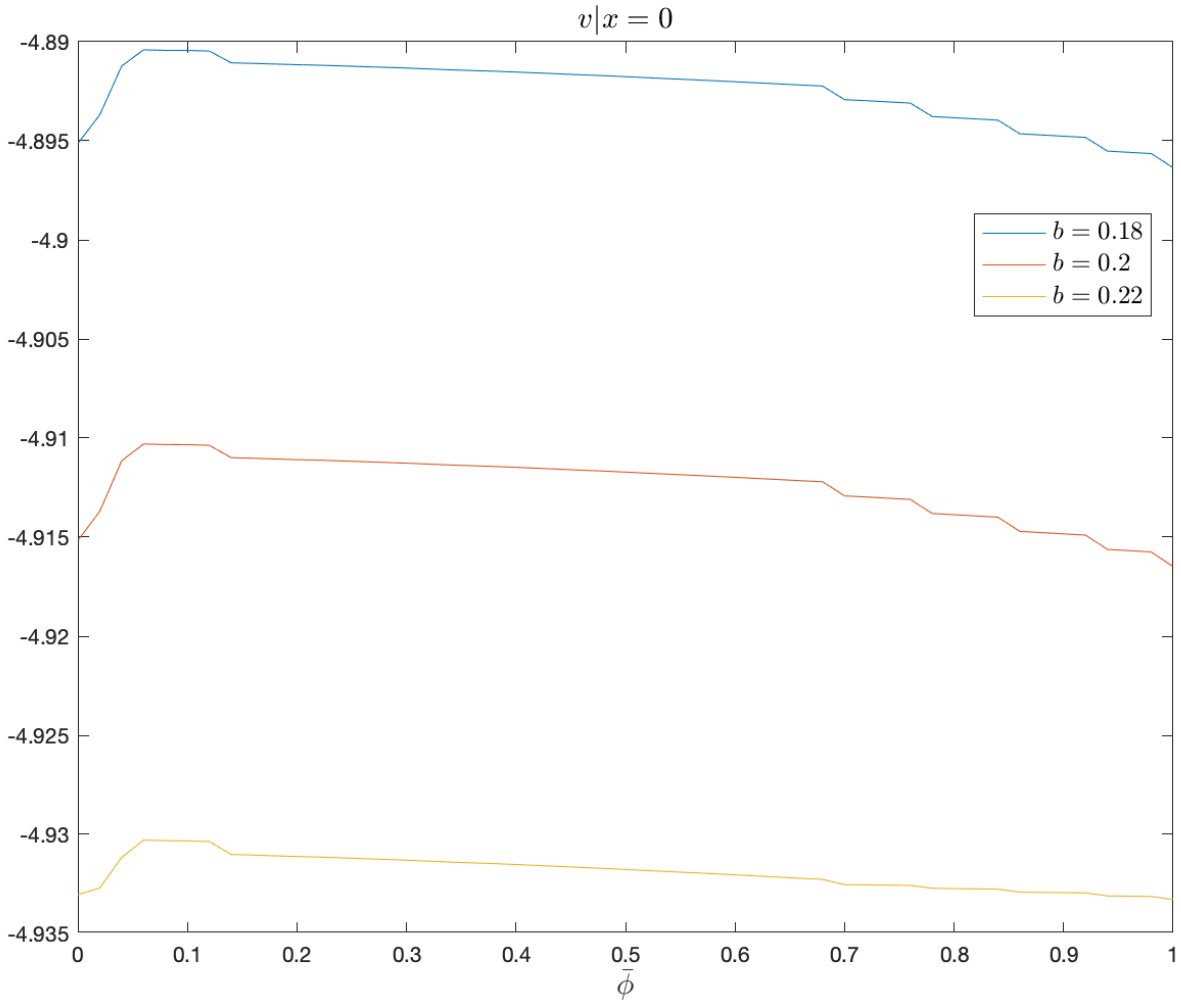
$$v^R(b,\bar{\phi},s) = \max_{b^n} u\left(1-(1-x1_{b\geq 0}\bar{\phi})b + q(b^n,\bar{\phi},s)b^n\right) + \beta E_s\left[v(e^{x'd-g'}b^n,\bar{\phi},s')e^{(1-\gamma)(g'-x'd)}\right]$$

$$q(b^n \geq 0,\bar{\phi},s) = \frac{1}{1+r}\Pr_s\left[\text{repay}\left((1-x'\bar{\phi})e^{x'd-g'}b^n\right)\right] \underbrace{-\frac{\bar{\phi}p_x}{1+r}\Pr\left[\text{repay}\left((1-\bar{\phi})e^{d-g'}b^n\right)|g,x'=1\right]}_{\text{relief (insurance) premium}}$$

- P1: A constrained planner chooses $\bar{\phi}$

$$\max_{\bar{\phi}} v\left(b,\bar{\phi},g,x=0\right)$$

Optimal relief



- $\bar{\phi}^* \approx 0.10$

Experiment 2: Markov debt relief

- P2: Planner finds relief policy *function* $\phi(\cdot)$ *recursively*

$$v_o^R(b,s) = \max_{\phi} \max_{b^n} u\left(1 - b + q(b^n, \phi, s) b^n\right) + \beta E_s \left[v_o \left((1 - x' 1_{b^n \geq 0} \phi) e^{x'd - g'} b^n, s' \right) e^{(1-\gamma)(g' - x'd)} \right]$$

$$q(b^n \geq 0, \phi, s) = \frac{1}{1+r} \Pr_s \left[\text{repay} \left((1 - x'\phi) e^{x'd - g'} b^n \right) \right] - \underbrace{\frac{\phi p_x}{1+r} \Pr \left[\text{repay} \left((1 - \phi) e^{d - g'} b^n \right) | g, x' = 1 \right]}_{\text{relief premium}}$$

Relief Laffer curve[1]

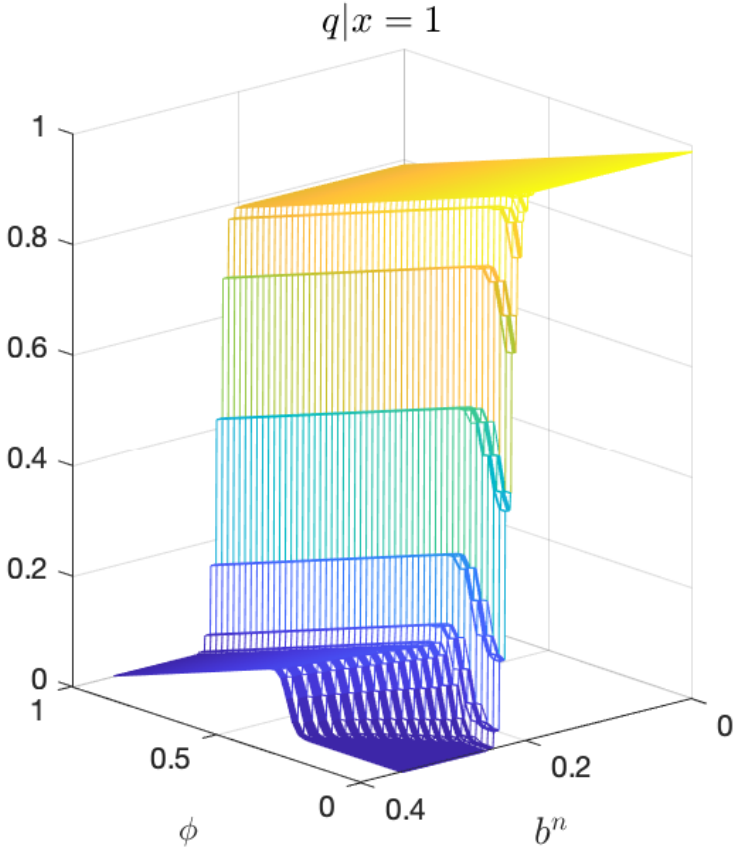
Proposition 3 (Nonmonotone effects of relief on bond price)

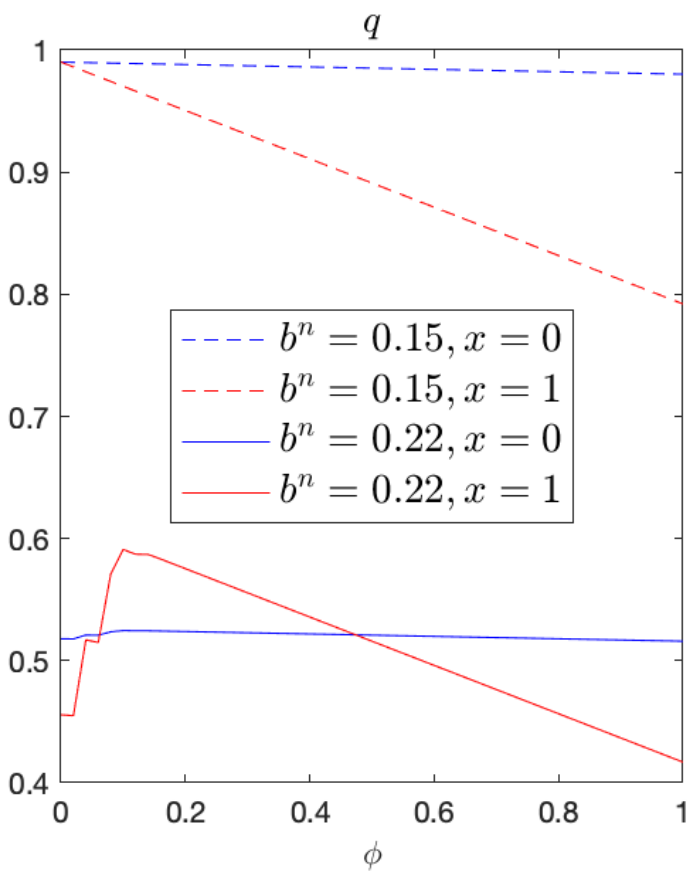
Assume iid g

$$\bullet \frac{\partial q}{\partial \phi} = \frac{p_x}{1+r} \left\{ \underbrace{f_g\left(\ln \frac{(1-\phi)e^d b^n}{b_1^*}\right)}_{\textit{effect on repayment prob}} - \underbrace{(1 - F_g\left[\ln \frac{(1-\phi)e^d b^n}{b_1^*}\right])}_{\textit{effect on relief premium}} \right\}$$

$$\bullet \frac{\partial q}{\partial \phi} > 0 \iff \underbrace{\underbrace{h_g}_{\textit{hazard rate}} \left(\ln \frac{(1-\phi)e^d b^n}{b_1^*}\right)}_{\textit{rate country fails to repay in disaster}} > 1.$$

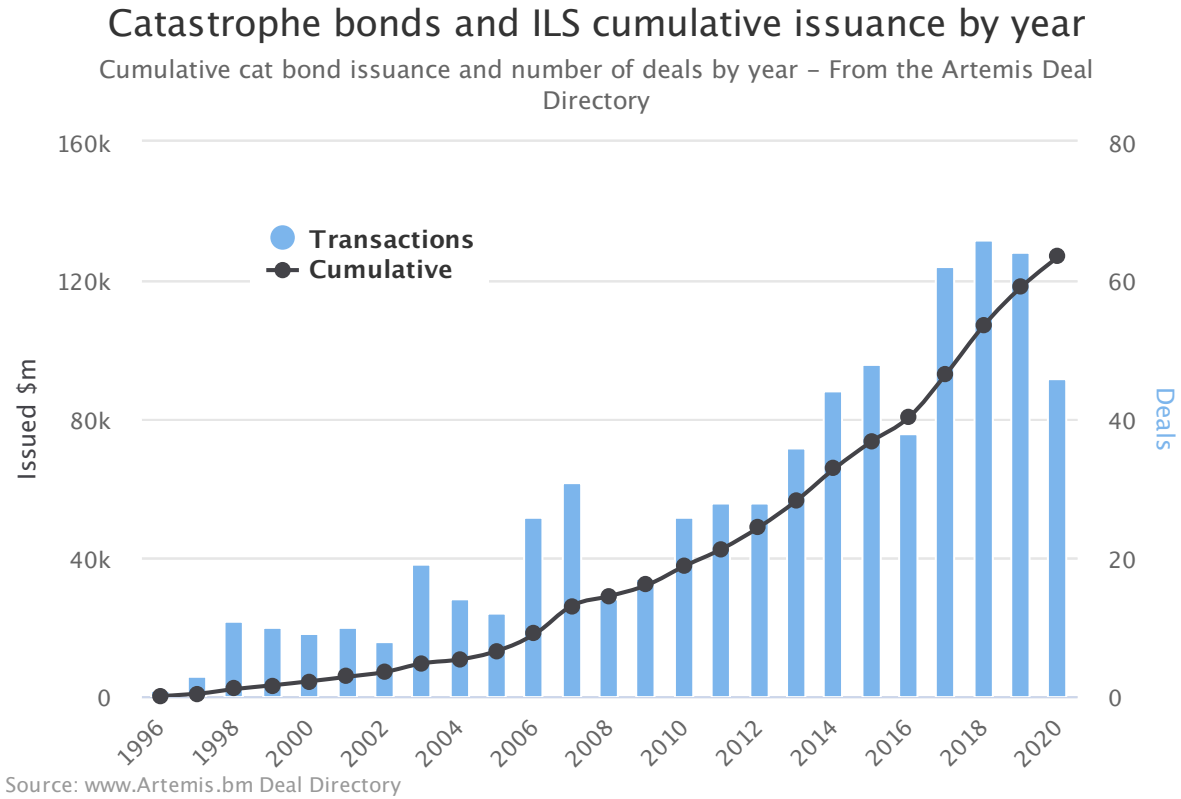
[1] Krugman (1988): "just as governments may sometimes actually increase tax revenue by reducing tax rates, creditors may sometimes increase expected payment by forgiving part of a country's debt"


$q|x = 1$
1
0.8
0.6
0.4
0.2
0
1
0.5
0
ϕ
0.4
0.2
0
b^n


q
1
0.9
0.8
0.7
0.6
0.5
0.4
0
0.2
0.4
0.6
0.8
1
ϕ
$b^n = 0.15, x = 0$
$b^n = 0.15, x = 1$
$b^n = 0.22, x = 0$
$b^n = 0.22, x = 1$

Experiment 3: Catastrophe (or act-of-God) bonds

- Additional instrument: bonds whose face value $\to 0$ if $x = 1$ (disaster as trigger event)
  - E.g., bonds with hurricane clause (Grenada 2015)



- Equivalent: country chooses $b^n = \frac{B' + B^{CAT'}}{Y}$ & $\theta' := \frac{B^{CAT'}}{B' + B^{CAT'}}$.

$$\text{P3: } v^R_{cat}(b,s) = \max_{b^n, \theta'} u\left(1 - b + q(b^n, \theta', s) b^n\right) + E_s\left[v_{cat}\left((1 - x' 1_{b^n \geq 0} \theta') e^{d-g'} b^n, s'\right) e^{(1-\gamma)(g'-x'd)}\right]$$

$$q(b^n \geq 0, \theta', s) = \frac{1}{1+r} \Pr_s\left[\text{repay } (1 - x\theta') e^{x'd-g'} b^n\right] - \underbrace{\frac{\theta' p_x}{1+r} \Pr\left[\text{repay } (1-\theta') e^{d-g'} b^n \mid g, x' = 1\right]}_{\text{insurance premium}}$$

Lemma 1 ("Decentralization")

An allocation solves optimal relief problem P2 iff it solves optimal problem with CAT bonds P3.

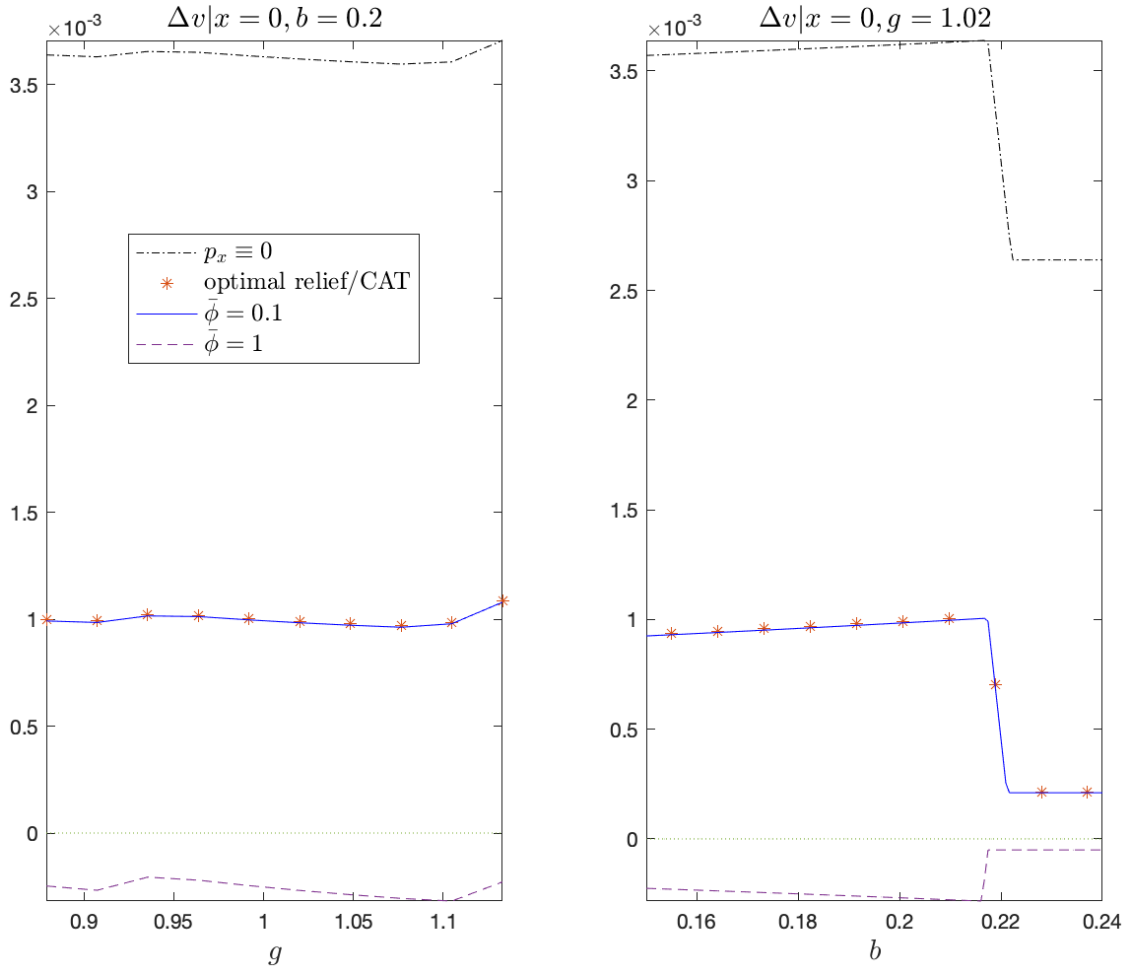
Optimal demand for CAT bonds

- FOC of CAT bond fraction θ':

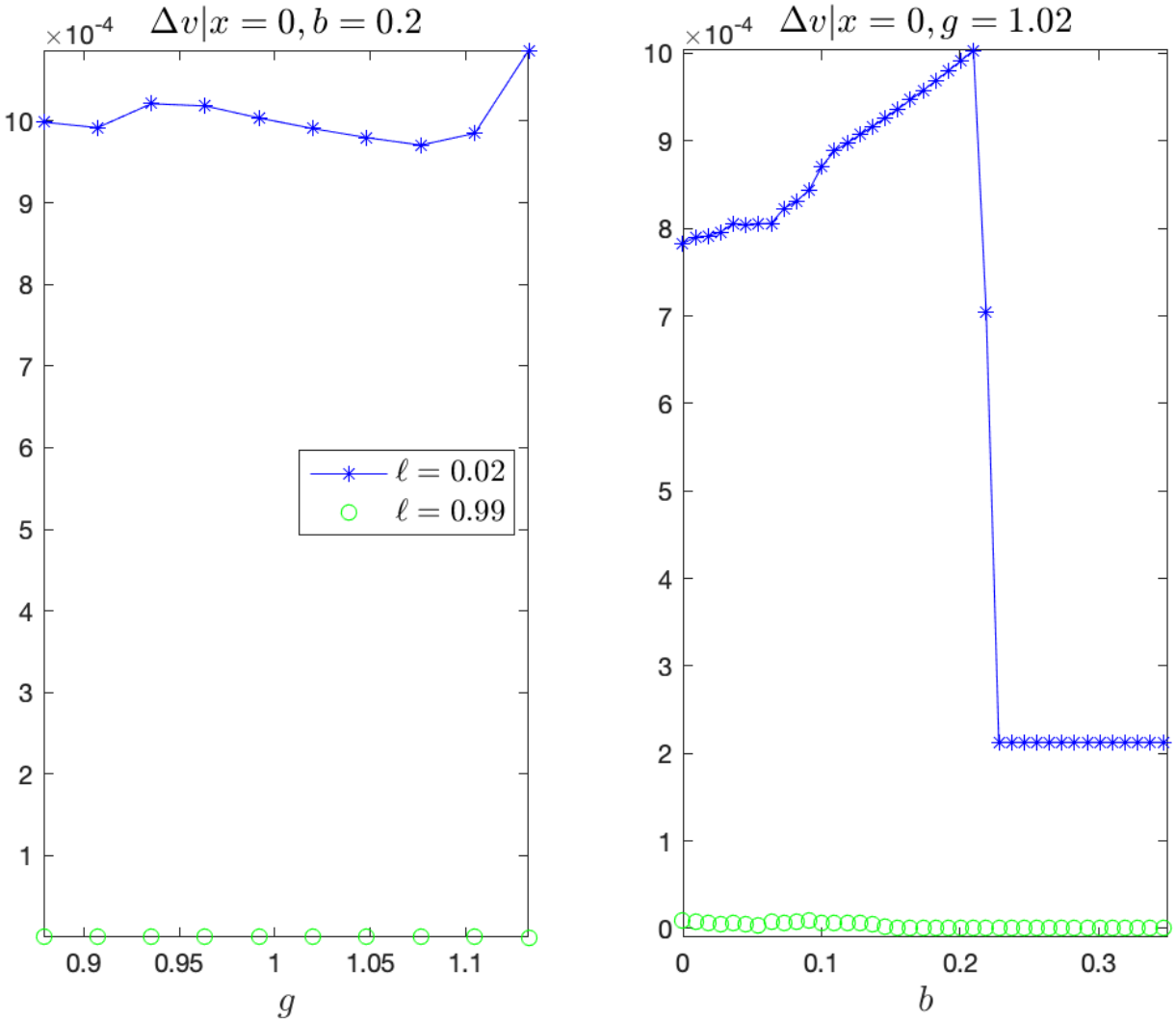
$$\underbrace{\beta(1+r)E\left[\left(\frac{e^{g'}c'}{c}\right)^{-\gamma}|\text{repay}, x'=1\right]}_{\text{insurance benefit}} + \underbrace{h_g\left(\ln\frac{(1-\theta')e^d b^n}{b_1^*}\right)}_{\text{benefit of reducing default risk}} = 1$$

  - Insurance benefit is conditional on repayment
  - Additional benefit of CAT bonds: reduce strategic default risk
    - ★ Absent in models without strategic default (e.g., Borensztein Cavallo Jeanne 2017).

Welfare gain ($\Delta v := \frac{v - v_{\bar{\phi}=0}}{|v_{\bar{\phi}=0}|}$)



- Simple optimal $\bar{\phi}$ works nearly as well as optimal ex-ante ϕ_0
- Welfare gain from CAT bonds $\approx$ 30% of gain from completely eliminating disaster risk



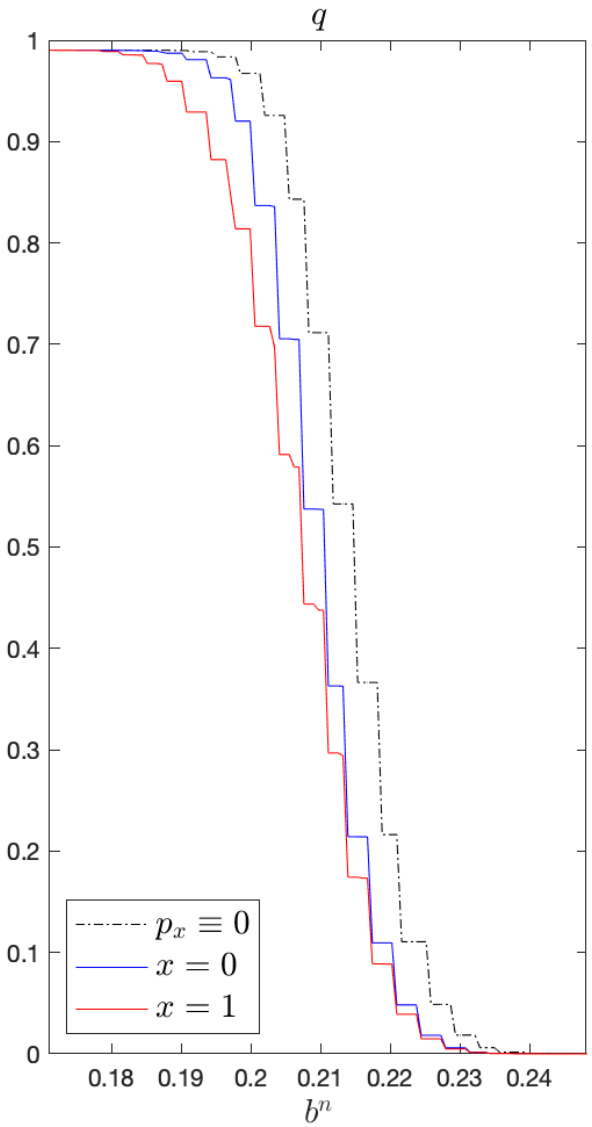
- Explicit modeling of strategic default is critical for welfare analysis of disaster-contingent bonds:
  - Large welfare gain is driven by reduction in default risk
  - Gain≈ 0 in environment without default risk ($\ell = 0.99$)

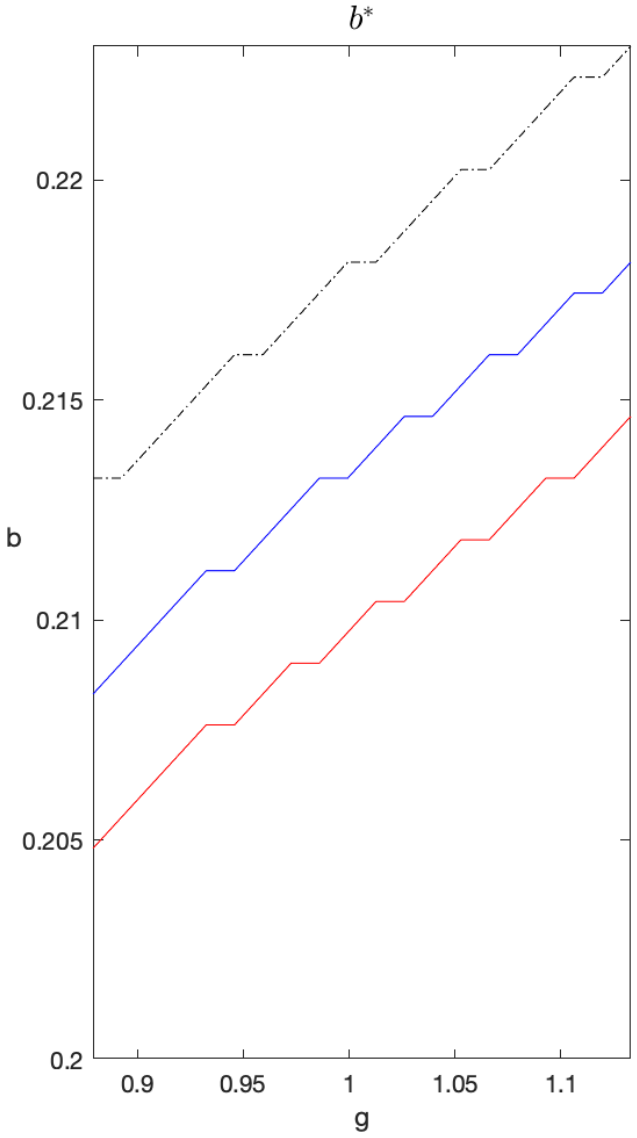
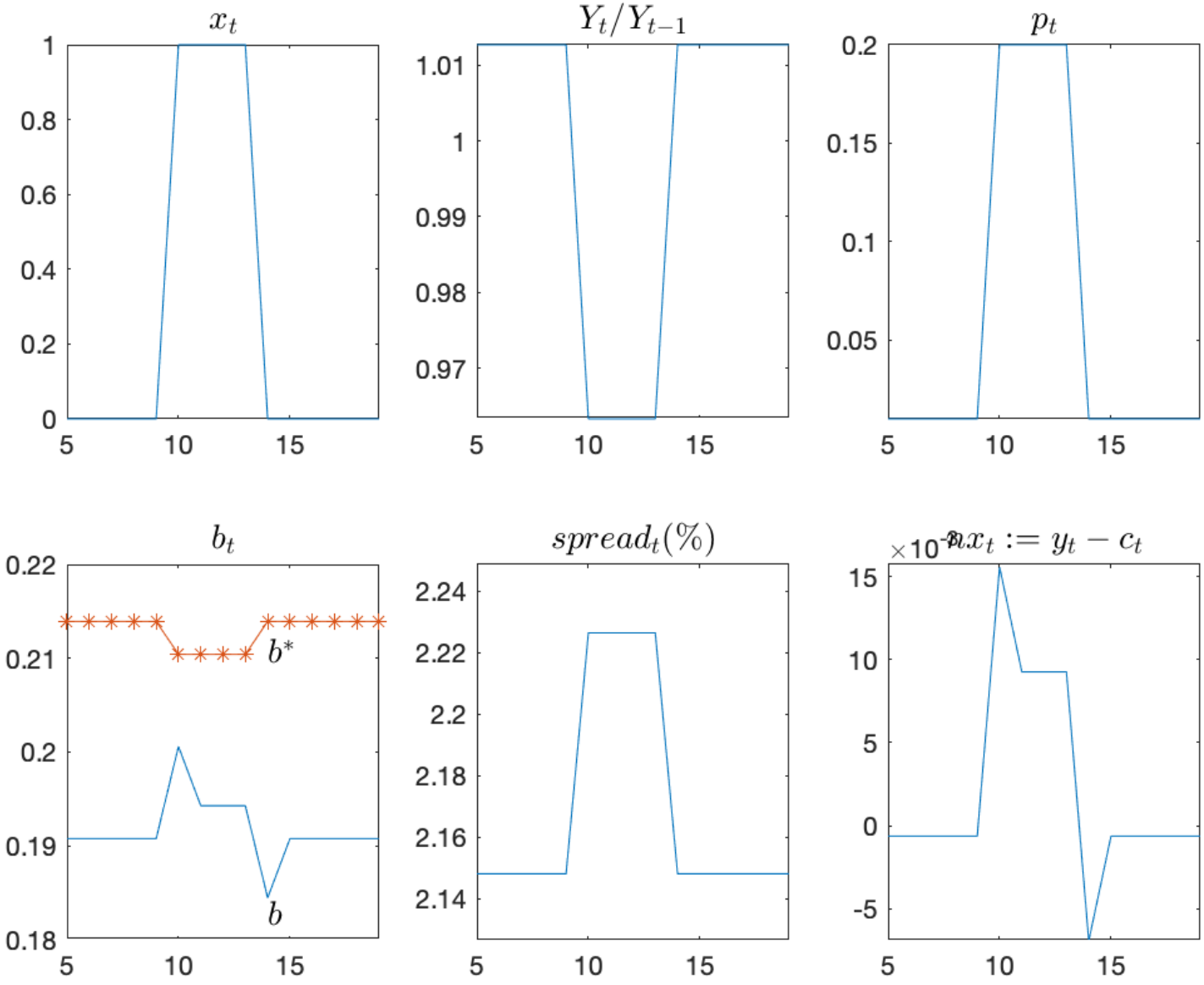
Conclusion

- We characterize
  1. Effects of disaster risk on sovereign default risk
  2. Effects of disaster-contingent policies/assets
     - ★ Explicit modeling of strategic default is critical here
- Work in progress:
  - **Capital**
  - Global disasters
  - EZ preferences

Disaster reduces debt sustainability

Quantitative illustration (Aguiar Gopinath parameters + $p_0 = 1\%, p_1 = 20\%, d = 5\%$)





Impulse responses