Economica LSE Department of Economics

2014 *Economica* Phillips Lecture

Environmental Protection and Rare Disasters

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Environmental Protection, Rare Disasters, and Discount Rates

Robert J. Barro

Low Discount Rates?

- Discount rates play central role in *Stern Review* and related literature. Spending money now to reduce environmental pollution modeled as generating benefits in distant future.

- Policy tradeoff depends on whether benefits discounted at substantial rate, such as 5-6% rate on private capital, or near-zero social rate advocated by *Review*. Many economists criticized assumption of near-zero discount rate.

Uncertainty

- *Review* stresses uncertainty about environmental damages, including links with policies: “Uncertainty about impacts strengthens the argument for mitigation; this Review is about the economics of the management of very large risks.”

- But baseline model deterministic. Impossible to think about what discount rate appropriate.

Fat Tails

- Weitzman emphasizes that treatment of uncertainty crucial for environmental issues because of fat-tailed nature of potential environmental crises.

- Important not just to determine magnitudes of discount rates relevant for capitalizing future costs and benefits. Central feature of social investments is influence on probability of associated rare disasters.

- Two key relationships: how much is it worth to reduce probability of environmental disaster and how much does investment lower this probability?

Rare Macro Disasters

- Fat tails imply risk aversion central. Use evidence on sizes of rare macro disasters (wars, financial crises, disease epidemics) to calibrate potential size of environmental damages?
- Want framework, such as that of Epstein & Zin, that distinguishes risk aversion from substitution over time. First is central, second minor.
- Use evidence from rare macro disasters on size of risk-aversion coefficient.

Weitzman

My approach consistent with Weitzman insight:

“spending money now to slow global warming should not be conceptualized primarily as being about optimal consumption smoothing so much as an issue about how much insurance to buy to offset the small chance of a ruinous catastrophe”

Dynamics

- Optimal choice of environmental policy as decision about how much to spend to reduce probability (or potential size) of environmental disasters.
- Policy choice features spending now to gain later, because lowering today’s disaster probability improves outcomes for indefinite future.
- Main tradeoff does not involve dynamic where optimal ratio of environmental investment to GDP and disaster probability look different today from tomorrow.
- In my main model, investment ratio and disaster probability constant, although levels depend on present-versus-future tradeoff.
- Extensions may generate path of gradually rising investment ratio.

Preview Results on Discount Rate

- Connection with environmental investment and disaster probability depends on source of change in rate. If pure rate of time preference changes, results as in *Stern Review*.

- Results different if change in rate reflects risk aversion or size distribution of disasters. These changes impact benefit from changing probability of disaster as well as discounting.

Model as in Rare Macro Disasters

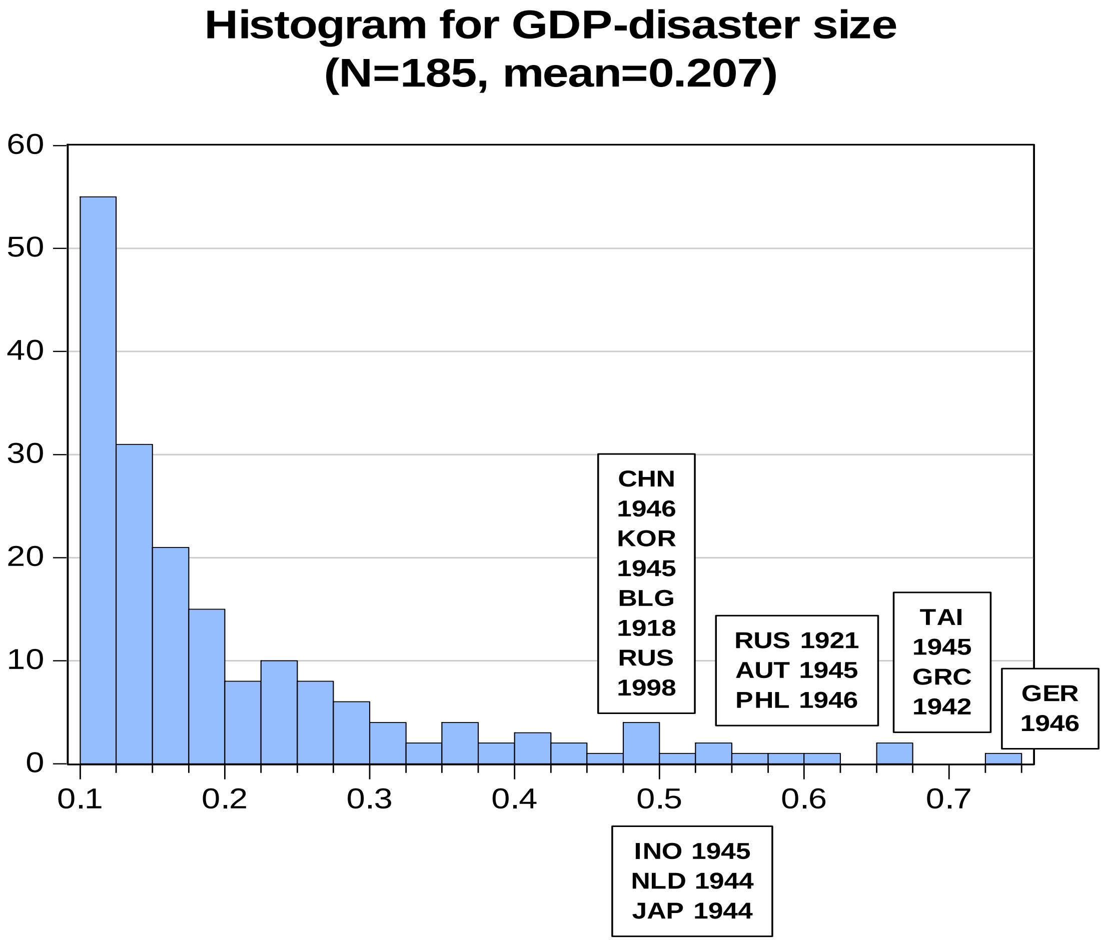
Formal model parallels rare-disaster approach, as in Barro (2009):

$$(1) \qquad log(Y_{t+1}) = log(Y_t) + g + u_{t+1} + v_{t+1}$$

i.i.d. shocks. Main part that matters is disaster shock, v, associated with probability p and size b.

$$(2) \qquad g^* = g + (1/2)\sigma^2 - p \cdot Eb$$

GDP Disasters



Disaster Probabilities

(3) $p = \pi + q$

π is probability of non-environmental disaster, as in previous work.

q is probability of environmental disaster (modeled as v-shock; Y, C down).

b distribution assumed same for both.

Epstein-Zin Utility

(4)

$$U_t = \frac{\left\{ C_t^{1-\theta} + \left(\frac{1}{1+\rho}\right)\left[(1-\gamma)E_t U_{t+1}\right]^{(1-\theta)/(1-\gamma)} \right\}^{(1-\gamma)/(1-\theta)}}{(1-\gamma)}$$

Recursive form.

γ is CRRA, around 3-4,

$1/\theta = IES > 1$.

$\gamma = \theta$ is usual power utility.

Environmental Investment

(5) $C_t = (1-\tau)\cdot Y_t$

τ is ratio of environmental investment to GDP.

(6) $q = q(\tau) = q(0)\cdot e^{-\lambda\tau}$

$\lambda>0$, $q'(\tau) < 0$. Assume $\tau=0$ historically.

- Semi-elasticity of q w.r.t. τ is constant, $-\lambda$.

- Important factor is derivative of q w.r.t. τ, which equals $-\lambda q = -\lambda q(0) \cdot e^{-\lambda\tau}$. Takes on finite value $-\lambda q(0)$ at $\tau=0$. Falls to $-\lambda q(0) \cdot e^{-\lambda}$ at $\tau=1$.

- Key parameters are λ and $q(0)$. τ optimally set as constant, which equals zero if $\lambda q(0)$ below critical value.

Lucas Trees

- Frame results in terms of prices of Lucas trees, which provide stream of per capita consumption, C_t.

- *V* is price-dividend ratio for equity claims on trees. With i.i.d. shocks, V constant. Reciprocal (dividend-price ratio) is

$$(8) \qquad 1/V = \rho - (1-\theta)g^* + (1/2)\gamma(1-\theta)\sigma^2 + p\left(\frac{1-\theta}{\gamma-1}\right)[E(1-b)^{1-\gamma} - 1 - (\gamma-1)Eb]$$

θ<1 implies V lower if uncertainty greater (higher σ or p or outward shift of b-distribution). Also implies that rise in g^* increases V.

$$(9) \qquad 1/V = r^e - g^*,$$

where r^e is expected rate of return on unlevered equity. Condition $r^e > g^*$ is transversality condition; guarantees that market value of tree positive and finite.

- Formula for 1/V in terms of g:

$$1/V = \rho - (1-\theta)g + (1/2)(1-\theta)(\gamma-1)\sigma^2 + p\left(\frac{1-\theta}{\gamma-1}\right)[E(1-b)^{1-\gamma} - 1]\,. \tag{10}$$

- Note that affecting p = *π + q* isomorphic to affecting disaster size—multiply (1-b) by some factor, given shape of distribution.

- Attained utility at date t (up to positive, monotonic transformation) is

$$U_t = \left(\frac{1}{1-\gamma}\right) V^{(1-\gamma)/(1-\theta)} (1-\tau)^{1-\gamma} Y_t^{1-\gamma} . \tag{11}$$

- U_t increasing in V if $\theta<1$, decreasing in τ (given V), increasing in Y_t.

- Government’s optimization problem is to choose τ (more generally, path of τ) to maximize U_t in (11). Government at each date *t* advances interests of representative household alive at *t*; respects rep. household’s vision of utility, including ρ (and ρ *).

- Tradeoff that determines τ is direct consumption loss today weighed against benefits for entire path of future consumption from decrease in today’s disaster probability. (Note: disasters permanent to levels.)

First-Order Condition

- When optimal solution for τ interior, τ determined from F.O.C.:

(12) $\frac{1}{V} = r^e - g^* = \left(\frac{1-\tau}{\gamma-1}\right) \cdot [E(1-b)^{-\gamma} - 1] \cdot \lambda q(0) e^{-\lambda\tau}$

- Dividend-price ratio, on left (given in [10]), correct measure in model of required rate of return on environmental investment. (Note: environmental disaster modeled as lowering GDP and C.)

- Far right of (12) reflects benefit at margin from negative effect of τ on environmental disaster probability, q. λq is magnitude of derivative of q w.r.t. τ.

- Marginal benefit on right larger when CRRA, γ, higher (because $1-b$ term dominates), or distribution of disaster sizes, b, shifted out, or baseline probability of environmental disaster, $q(0)$, higher.

Consumer Surplus

- Consumer surplus from government's opportunity to carry out environmental investment at optimal ratio, τ^*, rather than $\tau=0$.
- Let Y_t^0 and U_t^0 be values of Y_t and U_t corresponding to $\tau=0$. Let Y_t^* be Y_t that yields same utility, U_t^0, when $\tau=\tau^*$, so that $Y_t^* \leq Y_t^0$. Society willing to give up GDP today to carry out investment forever at optimal ratio.

- Formula:

$$\text{(14)} \qquad \frac{Y_t^*}{Y_t^0} = (\frac{V^0}{V^*})^{\frac{1}{1-\theta}} \cdot (\frac{1}{1-\tau^*})$$

$(1 - \frac{Y_t^*}{Y_t^0})$ is proportionate fall in today’s GDP that society would accept to gain opportunity to choose τ optimally forever, rather than $\tau=0$.

Calibration

- Calibration uses parameters in Table 1. Note $\gamma=3.3$, disaster prob. = 0.040 per year, Eb=0.21.
- 5349 annual GDP observations for 40 countries. 185 disaster events with peak-to-trough contractions of 10% or more.
- No environmental disasters in sample. Use q(0)=0.010 per year in baseline.

Table 1:
Baseline Parameter Values

Parameter	Value
γ (coefficient of relative risk aversion)	3.3
θ (inverse of *IES* for consumption)	0.5
σ (s.d. of normal shock per year)	0.020
g (growth rate parameter per year)	0.025
g^* (expected growth rate)	0.017
Eb (expected disaster size in disaster state)	0.21
$E(1\text{-}b)^{-\gamma}$ (expected marginal utility in disaster)	2.11
$p(0)=\pi+q(0)$ (probability per year of disaster)	0.040
$q(0)$ baseline prob. of environmental disaster	0.010
r^f (risk-free rate per year)	0.010
r^e (expected return on unlevered equity)	0.059
ρ (pure rate of time preference per year)	0.044
ρ^* (effective rate of time preference per year)	0.029

Table 2: Optimal τ

λ: semi-elasticity of q with respect to τ	τ	q: environmental disaster probability	consumer-surplus ratio
I (baseline): γ=3.3, empirical size distribution of disasters, q(0)=0.010, ρ=0.044			
≤ 8.63	0	0.010	0
10	0.014	0.0087	0.001
15	0.036	0.0058	0.012
20	0.042	0.0043	0.024
50	0.035	0.0017	0.060
100	0.025	0.0008	0.080
II: γ (coefficient of relative risk aversion) = 5.0			
≤ 4.81	0	0.010	0
7	0.051	0.0070	0.011
10	0.071	0.0049	0.034
15	0.076	0.0032	0.065
20	0.072	0.0024	0.087
50	0.048	0.0009	0.139
100	0.031	0.0004	0.163

Table 2, continued

λ: semi-elasticity of q with respect to τ	τ	q: environmental disaster probability	consumer-surplus ratio
III: disaster sizes multiplied by 1.1			
≤ 6.76	0	0.010	0
7	0.005	0.0097	0.000
10	0.038	0.0068	0.009
15	0.052	0.0046	0.028
20	0.054	0.0034	0.044
50	0.041	0.0013	0.088
100	0.027	0.0007	0.109
IV: q(0) (baseline environmental disaster probability) = 0.005			
≤ 17.3	0	0.005	0
20	0.007	0.0043	0.001
50	0.021	0.0018	0.017
100	0.018	0.0008	0.030

Table 2, continued

λ: semi-elasticity of q with respect to τ	τ	q: environmental disaster probability	consumer-surplus ratio
V: ρ (rate of time preference) = 0.030			
≤ 5.65	0	0.010	0
7	0.029	0.0082	0.003
10	0.055	0.0058	0.019
15	0.064	0.0038	0.045
20	0.063	0.0028	0.064
50	0.044	0.0011	0.112
100	0.029	0.0006	0.135
VIa: θ (1/IES) = 1.0			
≤ 9.20	0	0.010	0
10	0.008	0.0092	0.0003
15	0.031	0.0063	0.009
20	0.037	0.0048	0.019
50	0.033	0.0019	0.053
100	0.024	0.0009	0.072
VIb: θ (1/IES) = γ = 3.3			
≤ 11.79	0	0.010	0
15	0.013	0.0082	0.002
20	0.022	0.0064	0.007
50	0.026	0.0027	0.031
100	0.020	0.0014	0.046

Baseline Results

- Given $q(0)$, (12) inconsistent with $\tau>0$ if λ below a threshold. For baseline parameters, threshold is 8.6. Table 2, Section I, shows $\tau=0$ for $\lambda\leq 8.6$.

- For λ above threshold, τ positive. τ initially rises with λ, then falls—because higher λ means q in (7) smaller for given τ. τ reaches 0.014 at $\lambda=10$, 0.036 at $\lambda=15$, and 0.042 at $\lambda=20$, then falls to 0.035 at $\lambda=50$ and 0.025 at $\lambda=100$. Environmental disaster probability, q, declines monotonically with λ.

- Consumer-surplus ratio, from (14), in Table 2, Section I. Ratio = 0 until λ reaches threshold of 8.6, then rises with λ. At high λ, ratio substantial—2.4% of GDP when $\lambda=20$, 6.0% of GDP when $\lambda=50$.

- What is reasonable λ? $\lambda=10$ means increase in τ from 0 to 0.01 lowers q by about 10%; starting from $q(0)=0.010$, from 0.010 to 0.009. I cannot judge whether this response roughly correct or way too big or way too small.

Shifts in Parameters
Coeff. of Relative Risk Aversion

Table 2, Section II: γ rises to 5.0, compared to 3.3 in baseline. Effects both r^e-g^* (required return) and "marginal product" in (12). Latter effect dominates.

Large effect; threshold down to 4.8. For $\lambda=20$, when $\gamma=5$, $\tau=0.072$ ($q=0.0024$), compared to $\tau=0.042$ ($q=0.0043$) when $\gamma=3.3$. Higher γ raises environmental investment while simultaneously increasing required rate of return, r^e-g^*. (r^e rises from 0.059 to 0.072.)

Size Distribution of Disasters

- Outward shift in distribution of disaster sizes, *b*, similarly raises incentive to choose higher environmental investment. Table 2, Section III, shows effects from multiplication of each disaster size, *b*, by 1.1.

- This outward shift in disaster sizes lowers threshold λ to 6.8 from 8.6 in baseline. For $\lambda=20$, $\tau=0.054$ ($q=0.0034$) when disaster sizes larger by 10%, compared to baseline of $\tau=0.042$ ($q=0.0043$).

Baseline Environmental Disaster Probability

- Section IV of Table 2 assumes $q(0) = 0.005$, rather than 0.010. Lower $q(0)$ reduces incentive for environmental investment (right side of [12]). Threshold λ higher, 17.3, compared to 8.6 in baseline.

- Reasoning is that motivation to choose $\tau>0$ depends on magnitude of derivative of q w.r.t. τ at $\tau=0$, $-\lambda\cdot q(0)$. When $q(0)$ falls by one-half (from 0.010 to 0.005), λ has to double (from 8.6 to 17.3) to motivate positive environmental investment.

- When $\lambda=20$, $\tau=0.007$, compared to 0.042 in baseline. Thus, decrease in $q(0)$ from 0.010 to 0.005 produces large change in conclusions. What is reasonable $q(0)$?

Pure Rate of Time Preference

- Section V, Table 2 assumes rate of time preference, ρ, is 0.030, rather than baseline 0.044. Generates pure discounting effect emphasized in *Stern Review*. (8) implies dividend-price ratio, $1/V = r^e - g^*$, shifts down, so that marginal return from environmental investment has to be lower (when solution interior in [12]).

- Threshold λ declines to 5.6, compared to 8.6 in baseline. For $\lambda=20$, $\tau=0.063$, compared to 0.042 in baseline.

- Results in EZW model depend on effective rate of time preference, ρ^*. In baseline, $\rho^*= 0.029$. If $\rho=0.030$, $\rho^*=0.015$. Intuition about "reasonable" rate of time preference applies to ρ^*, not ρ? (Choice of ρ dictated by fitting data on returns, not ethical perspective.)

- Other changes equivalent to shift in ρ: σ^2, g, probability of non-environmental disaster, π. Effects tend to be small.

IES

- Change in *IES*, $1/\theta$, ambiguous effect on r^e-g^* in (8). Section VIa shows increase in θ from 0.5 to 1.0 raises threshold λ from 8.6 to 9.2. If $\lambda=20$, $\tau=0.037$ when $\theta=1$, compared to baseline of 0.042. Hence, minor impact.

- Section VIb has rise in θ to 3.3—equals γ and corresponds to usual power utility. Threshold λ rises to 11.8. If $\lambda=20$, $\tau = 0.022$, compared to 0.042 when $\theta=0.5$. Therefore, very large change in *IES* matters significantly for results. However, $\theta = 3.3$ unrealistically high because *IES* = 0.3 means price-dividend ratio, *V*, responds positively to increases in parameters related to uncertainty and negatively to growth-rate parameter, *g*.

- Overall, results support Weitzman's conjecture that optimal environmental investment not "primarily … about optimal consumption smoothing" (i.e. IES) "so much as an issue about how much insurance to buy to offset the small chance of a ruinous catastrophe" (key roles of CRRA and frequency and size distribution of disasters).

Uncertainty on Policy Effects

- Can allow for uncertainty in effects of policy, represented by λ. Eq. (12) replaced by:

(22) $\frac{1}{V} = r^e - g^* = \left(\frac{1-\tau}{\gamma-1}\right)[E(1-b)^{-\gamma} - 1]q(0) \cdot E(\lambda e^{-\lambda\tau})$

$\lambda e^{-\lambda\tau}$ replaced by its expectation. For example, λ takes on 2 values, λ_1 and λ_2, with probabilities that sum to 1.

- This uncertainty tends to lower τ (for given mean of λ) but effect not large? See Table 3.

Effects of Uncertainty about Policy Effectiveness

λ_1	λ_2	τ *(invest ratio)*	q *(disaster prob)*	cons. surplus ratio
10	10	0.0140	0.00869	0.00108
7.5	12.5	0.0133	0.00876	0.00102
5	15	0.0114	0.00894	0.00088
20	20	0.0415	0.00436	0.0237
15	25	0.0400	0.00458	0.0226
10	30	0.0353	0.00525	0.0197

Environmental Amenities

- Baseline has environmental disaster as large drop in GDP. Positive covariance with C implies relevant rate of return is r^e-g^*, which is high. But large benefit from reducing q.

- Weitzman criticized this standard approach:

> … there was never any deep economic rationale in the first place for damages from greenhouse gas warming being modeled as entering utility functions through the particular reduced form route of being a pure production externality …

- One alternative is *C* and *e* enter separably in household utility. Shock to *e* independent of shock to GDP and *C*?

- Differences from before are, first, required rate of return on environmental investment can be much lower, closer to risk-free rate.

- But, second, benefit from reducing q is much reduced. This effect dominates. Much weaker case than before for environmental investment.

Extensions

- In my model, optimal τ and q constant. Does not feature Nordhaus's ramp-up property; τ low in short run, high in long run. Might get this result if environmental damages function of past GDP with rising marginal effect as oceans eventually warm up.

- Results can be quantitatively consistent with arguments from *Review* about τ around 0.01. Different reasoning here.

- Results guided quantitatively by findings from rare macro disasters. Still leaves dependence on key parameters λ and *q(0)*.

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