Cooperation on Climate Change Mitigation

Charles Mason[a], Stephen Polasky[b] & Nori Tarui[c]

a: University of Wyoming, Economics & Finance

b: University of Minnesota, Applied Economics

c: University of Hawaii, Economics

Net global gains to CC IEA may be large, but benefit-cost ratio isn't…

Global benefits and costs of climate change mitigation

Benefits $283; Costs $92 (Billions 1990 USD)

Benefit-cost ratio 3.08

(Nordhaus and Boyer (2000) Warming the World: Economic Models of Global Warming; emission control rate 11%, CO2 concentration 1,170GtC, temperature +2.5% in 2100.)

Net global gains to CC IEA may be large, but benefit-cost ratio isn't…

By contrast…

Benefits and costs for the US of unilateral ozone policy

Benefits $3,575; Costs $21 (Billions 1985 USD)

Benefit-cost ratio 170

(EPA (1988) Regulatory Impact Analysis: Protection of Stratospheric Ozone)

Issues with IEAs

- Inherently dynamic
- Repeated interactions
- in a changing environment (“stock” pollutant)
- Nonlinear effects on damages
- Strategic interaction
- Any agreement to mitigate climate change must be self-enforcing

Previous literature 1

Treaty participation games (Barrett, Carraro, etc.)

- Stage 1: treaty participation, stage 2: emissions choice
- Analyze individually rational treaty participation
- By assumption, treaty members cooperate
- Two-stage or repeated games—no GHG dynamics

Previous literature 2

Dynamic models of climate change

- Many integrated assessment models (Nordhaus; Manne and Richels; Carraro)
- Most solve for globally optimal emissions control or a competitive eq’m
- Others solve for a Nash equilibrium, but with open-loop strategies (no intertemporal interactions)

Previous literature 3

Dynamic game models (Dutta and Radner)

- Dynamic game with GHG stock dynamics
- Solve for feedback, Markov perfect equilibria
- Support cooperation with trigger strategies
- Heterogeneous damages
- Countries' payoffs linear in GHG stock

Our Model

- Dynamic game with GHG stock dynamics
- Support cooperation as a subgame perfect eq’m outcome with threats of temporary sanctions followed by resumed cooperation
- Countries’ payoffs *nonlinear* in GHG stock

Assumptions

1. N countries choose GHG emissions $\{x_{it}\}$ in period t = 0, 1, . . . (infinite horizon)
2. Complete information, no uncertainty
3. Total emissions in period t:

$$X_t \equiv \sum_i x_{it}$$

4. 4 S_t : GHG stock in period t

$$S_{t+1} \equiv \lambda S_t + X_t$$

5. 1 − λ: natural decay rate ($0 < \lambda < 1$)

Assumptions, cont.

- Country i's periodwise return:

$$\Pi_i(x_{it}, S_t) = \pi_i(x_{it}) - d_i(S_t)$$

- Abatement cost convex, $\pi_i' > (<)\ 0$ for low (high) emissions
- Damage d_i: convex, increasing in stock
- δ: common discount factor

First-best outcome

- joint payoff is maximized

$$V(S) = \max \sum_i \pi_i(x_i, S) + \delta V(S')$$
$$s.t. \;\; S' = \lambda S + X$$

- Let $x^*(S) = \{x_i^*(S)\}$ be the optimal emission profile given S.
- Is there a SPE that delivers $x^*(S)$?

Simple Penal Strategy

- Phase I: Play $\{x_{i^*}\}$. If a single country j chooses over-emission, with resulting stock S', go to Phase II_j(S') next period; otherwise, repeat phase 1
- Phase II_j(S'): Countries play $x_j = (x^j_1, \ldots, x^j_N)$ for T periods. If a country k deviates with resulting stock S", go to Phase II_k(S"). Otherwise go back to Phase I.

Does this simple penal strategy yield a subgame perfect equilibrium?

yes, if:

- No country has an incentive to deviate in phase I
  (“No cheating”);
- Country j has no incentive to deviate in phase IIj
  (“No repeated cheating”);
- No country $i \neq j$ has an incentive to deviate in phase IIj **(“It pays to punish”)**;
- for all j and for all possible stock levels given initial stock S_0.

Candidate Penal strategy (symmetric case)

- Phase I: all countries play X*/N. If player *j* deviates in period *t*, then start Phase II_j in period *t*+1; otherwise return to Phase I:
- Phase IIj: Player j sets $x_{jt+1} = z$; Players $i \neq j$ play

$$x_{it+1} = [X_i^*(S_{t+1}) - z]/(N-1).$$

If player k deviates, start Phase II_k in period t+2; otherwise, return to Phase I.

Comparing payoff streams

Define $x^* = X^*/N$ and let

$S_{t+1}^* = \lambda S_t + X^*(S_t)$, pd. t+1 stock if coop'n in t

$S_{t+2}^* = \lambda S_{t+1}^* + X^*(S_{t+1}^*)$, pd. t+2 stock if coop'n in t,t+1

$S_{t+1}^d = \lambda S_t + X^* + x^d - X^*/N$, pd. t+1 stock if defect'n in t

$S_{t+2}^{d*} = \lambda S_{t+1}^d + X^*(S_{t+1}^d)$, pd. t+2 stock if defect'n in t, then coop'n in t+1

$S_{t+1}^{dp} = \lambda S_t + X^* + x^d - z$, pd. t+1 stock if defect'n in t (II_j)

X_j = combined emissions of countries $i \neq j$
= $X^* - x^*$ in phase I; $X^* - z$ in phase II_j;
$(N-2)X^*/(N-1) + z/(N-1)$ in phase II_k

Comparing payoff streams

$\pi^d(S)$ = one-time defection payoff given stock S

$= \pi(x^d(X_i,S),S) = \Pi(x^d(X_i,S)) – D(S)$

$\pi^p(S)$ = one-time punishment payoff given stock S

$= \pi(z,S) = \Pi(z) – D(S)$

$\pi^{dp}(S)$ = one-time defection payoff given stock S

(similar to π^d except different x^d)

v^* = j's value function if cooperate

v^d = j's value function if defect

v^p = j's value function if accept punishment

Comparing payoff streams

Phase I

- If cooperate:
  - $v^*(S_t) = \pi^*(S_t)+\delta\pi^*(S^*_{t+1})+\delta^2 v^*(S^*_{t+2}) = \pi^*(S_t)+ \delta v^*(S^*_{t+1})$
- If defect:
  - $v^d(S_t) = \pi^d(S_t)+\delta\pi^p(S^d_{t+1})+\delta^2 v^*(S^{d*}_{t+2}) = \pi^d(S_t)+ \delta v^p(S^d_{t+1})$

Phase II_j

- If cooperate:
  - $v^p(S_t) = \pi^p(S_t)+\delta\pi^*(S^*_{t+1})+\delta^2 v^*(S^*_{t+2}) = \pi^p(S_t)+\delta v^*(S^*_{t+1})$
- If defect:
  - $v^d(S_t) = \pi^{dp}(S_t)+\delta\pi^p(S^{dp}_{t+1})+\delta^{2\ v}*(S^{dp*}_{t+2}) = \pi^{dp}(S_t)+\delta v^p(S^{dp}_{t+1})$

Comparing payoff streams

Phase II_k

$\pi^{dpk}(S)$ = one-time defection payoff given stock S
(similar to above except third version of x^d)

v^{pk} = j's value function if j inflicts punishment

v^{dpk} = j's value function if j deviates (doesn't punish)

$S_{t+1}{}^{dpk} = \lambda S_t + X^* + x^d – (X^* - z)/(N-1)$, pd. t+1 stock if j $\neq$ k defects in t during phase II_k

- If cooperate:
  - $v^{pk}(S_t) = \pi^{pk}(S_t)+\delta\pi^*(S^*_{t+1})+\delta^2 v^*(S^*_{t+2}) = \pi^{pk}(S_t)+\delta v^*(S^*_{t+1})$
- If defect:
  - $v^{dpk}(S_t) = \pi^{dpk}(S_t)+\delta\pi^p(S^{dpk}_{t+1})+\delta^2 v^*(S^{dpk*}_{t+2}) = \pi^{dpk}(S_t)+\delta V^p(S^{dpk}_{t+1})$

Comparing payoff streams, cont.

Can show that:

- Increase in aggregate emissions following deviation by j is decreasing in X_j
  - Highest when j (lowest when i) deviates in II_j
- Temptation to defect is increasing in combined emissions of others
- Incentive constraint ‘tightest’ in Phase II_j

  $\therefore$ $v^d(S) - v^p(S)$ larger than other two gains
- Can determine SPE by inspecting constraint in II_j
  - Does not rely on symmetry
  - Can be extended to longer-lived punishment phases

Comparing temptations

- In each case, temptation to deviate is

$$\text{Gain} = \pi(x^d(X_j,S),S) + \delta v^p(S^d) - \pi^* - \delta v(S^*)$$

$$d\text{Gain}/dX_j = \partial[\delta v^p(S^*) - \pi^*]/\partial X_j + \{\partial[\pi^d + \delta v^p(S^d)]/\partial x^d\}\ \partial x^d/\partial X_j$$

$$= \delta v^{p\prime}(S^*) + \partial\pi^*/\partial x_j \text{ (since } X^* = X_j + x_j)$$

$$> 0 \text{ (since } = 0 \text{ at } x^d > x_j^*)$$

$\therefore$ Gain from deviation largest when X_j is largest

$\rightarrow$ Gain from deviation largest in II_j

Comparing payoff streams, cont.

- Increase in emissions declining in i's cooperative emissions, so largest in Phase II_j when j deviates and smallest in II_j when someone else deviates
  - Hence reduction in continuation payoffs larger following deviation in Phase II_j
- But increase in current payoffs largest for j in II_j
- Even with this conflict, can rank temptation

Symmetric LQ example

- Period-wise returns for each country:

$$\pi(x_{it}, S_t) = ax_{it} - bx_{it}^{\ 2} - dS_t^2$$

- Optimal cooperative emissions path:

$$V(S_t) = Max\ a\sum_{i=1}^{N} x_{it} - b\sum_{i=1}^{N} x_{it}^{\ 2} - NdS_t^{\ 2} + \delta V(S_{t+1})$$

First-best profile

- First-best choice of x_{it} must solve:

$$a - 2bx_{it}^* + \delta V'(S_{t+1}) = 0$$

- Summing over i:

$$Na - 2bX_t + N\delta V'(\lambda S_t + X_t) = 0$$

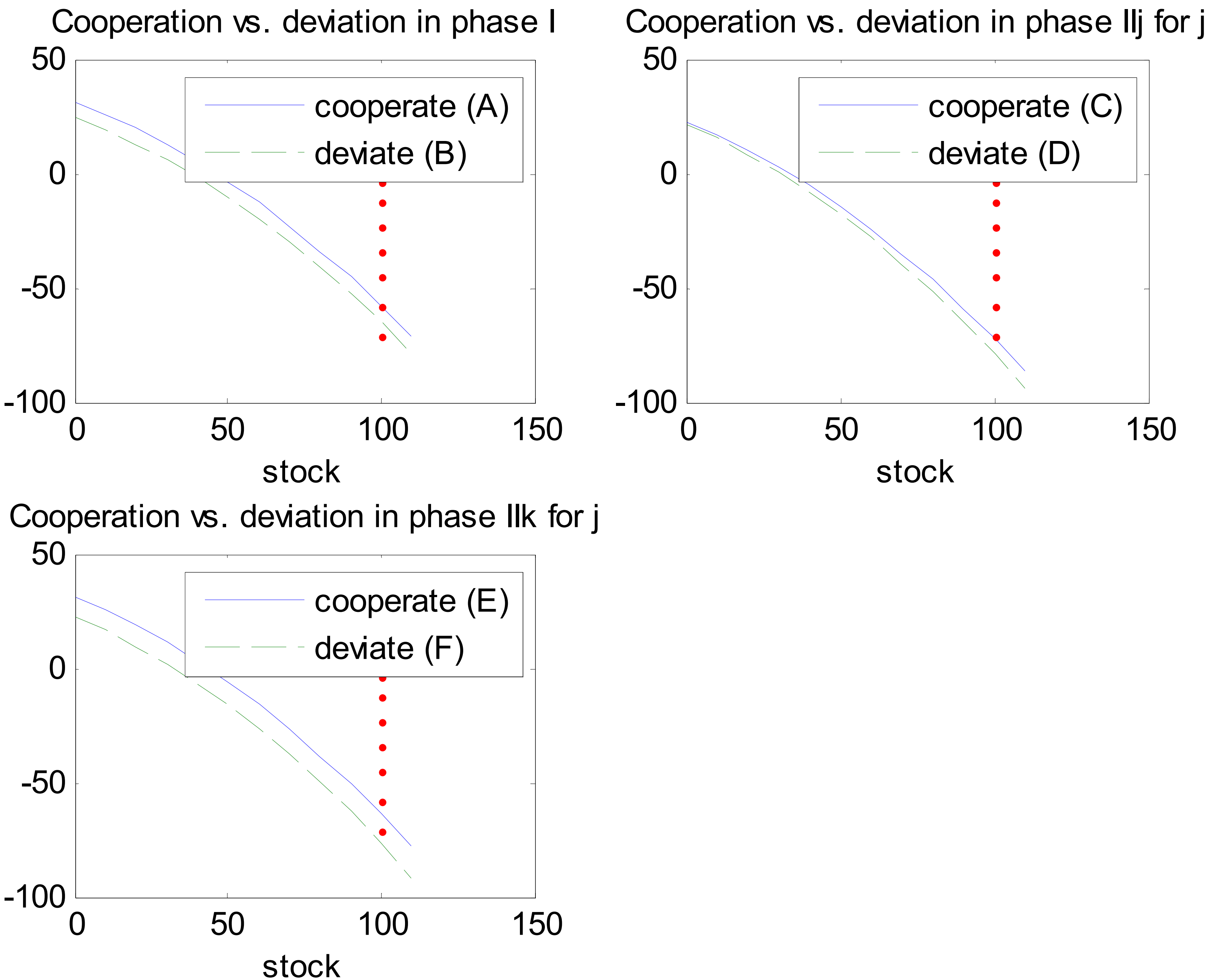
- Guess quadratic value, $V(S) = pS^2 + QS + R$; then $V'(S) = 2pS + Q$

First-best profile, cont.

- Insert into Bellman equation, combine terms to get:

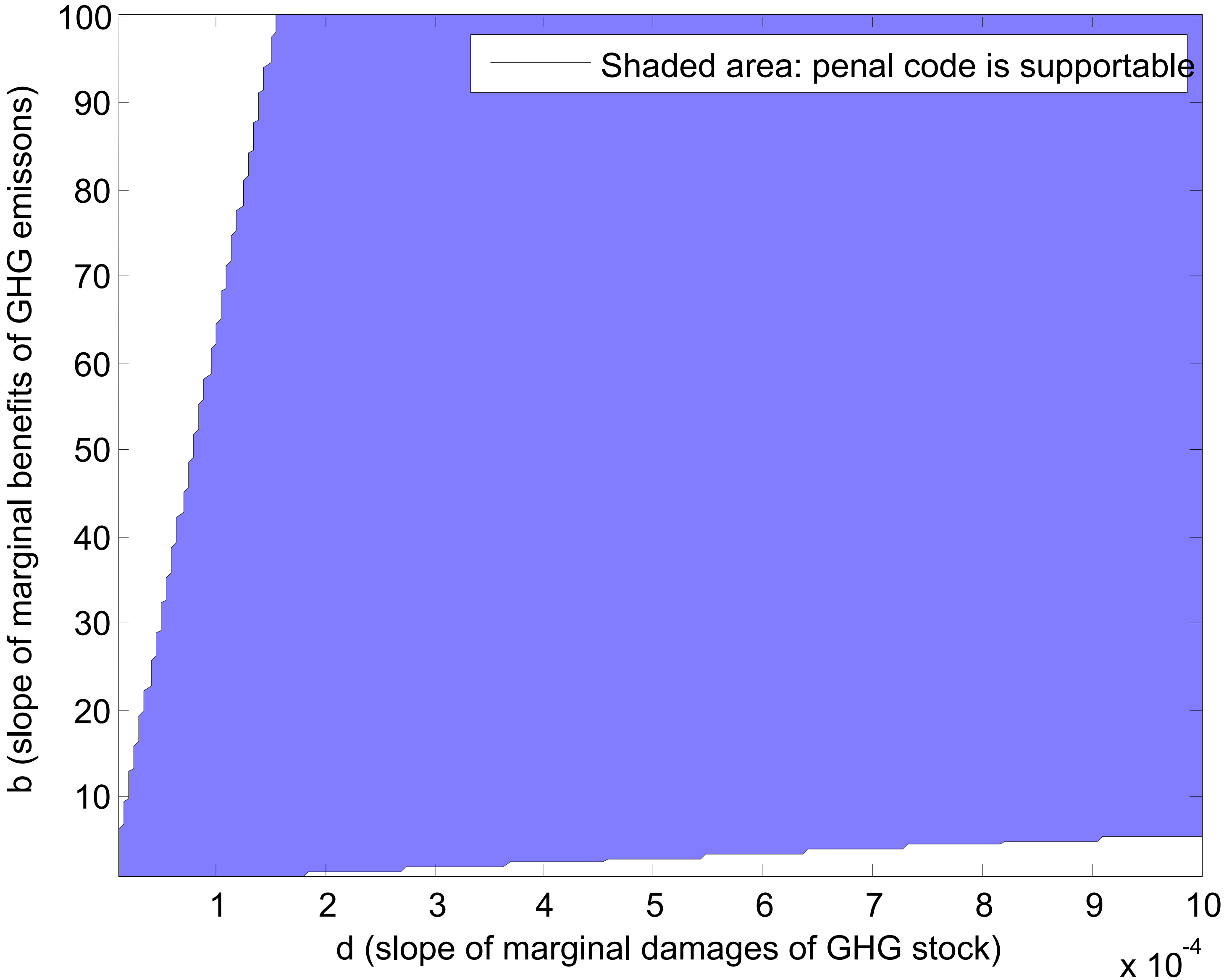
$$X_t^*(S_t) = \frac{N[a + 2\delta\lambda PS_t + \delta Q]}{2b - 2\delta NP}$$

- Insert into Bellman eq'n, gather factors in S and S^2, compare to Q and P…


Cooperation vs. deviation in phase I
cooperate (A)
deviate (B)
stock
Cooperation vs. deviation in phase IIj for j
cooperate (C)
deviate (D)
stock
Cooperation vs. deviation in phase IIk for j
cooperate (E)
deviate (F)
stock

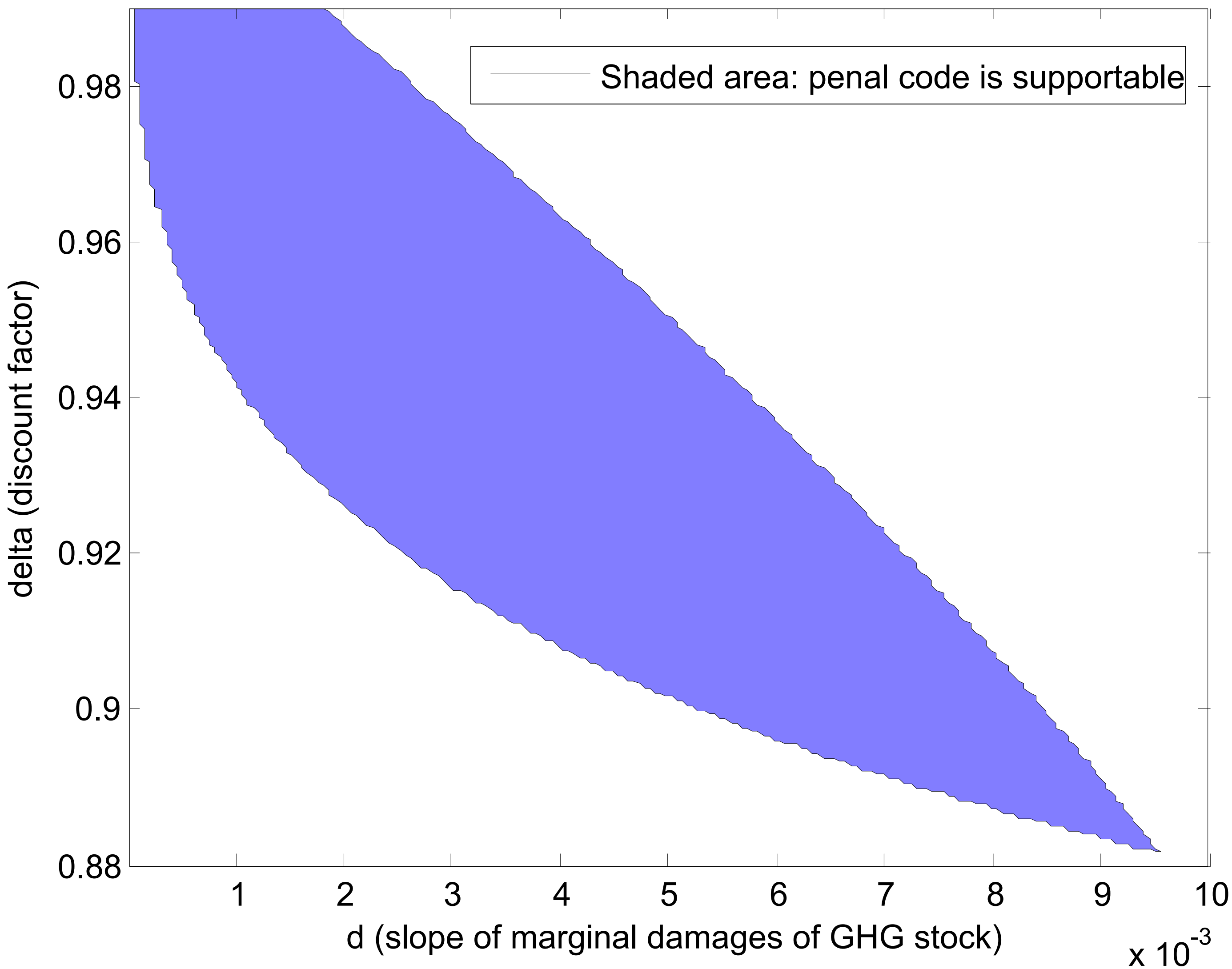
Example – SPE Penal code: b vs. d

LQ model: a=10, z=0, N=8, δ = .99



Example – SPE Penal code: b vs. d

LQ model: a=10, z=0, N=8, b = 1

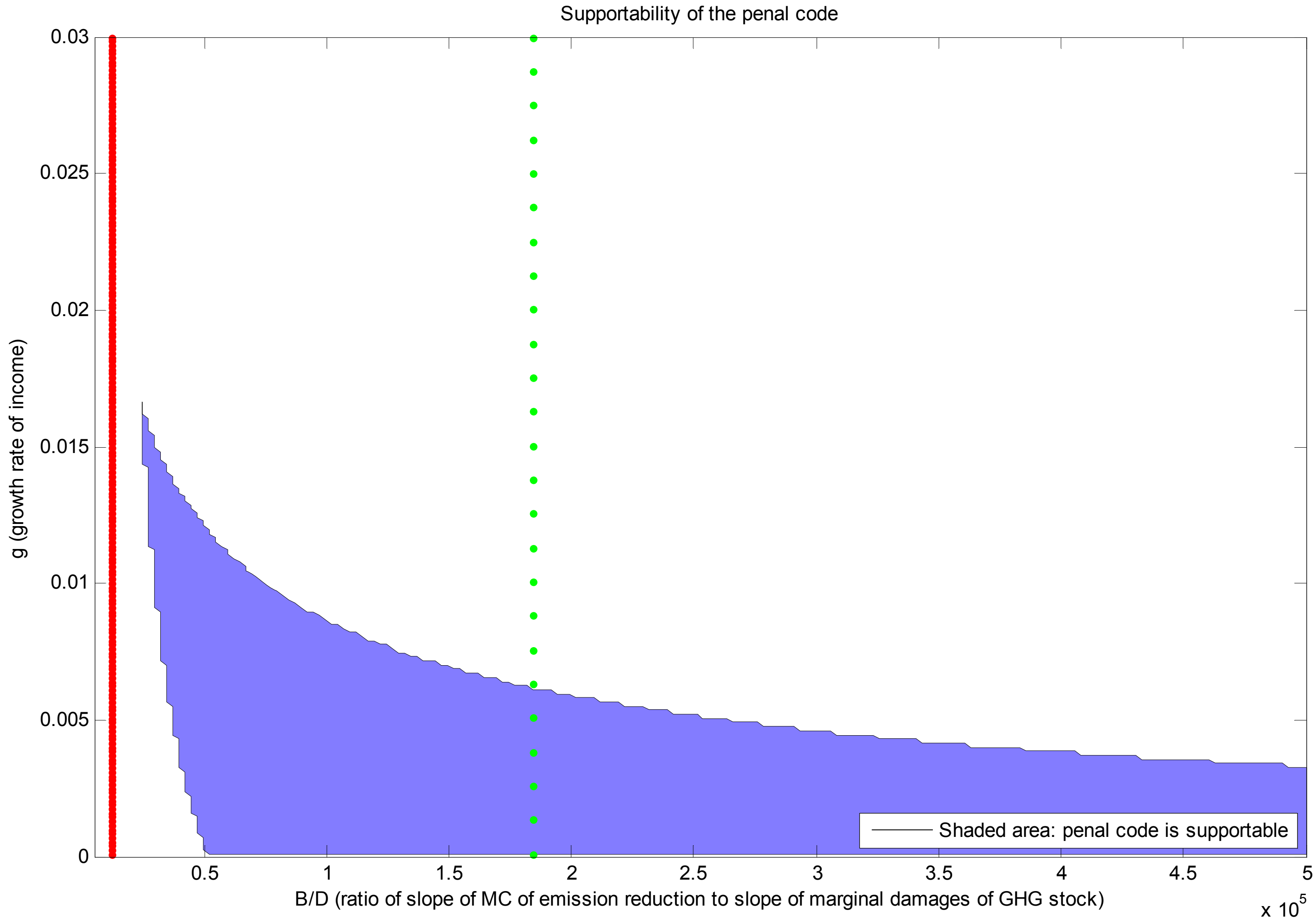


Looking ahead

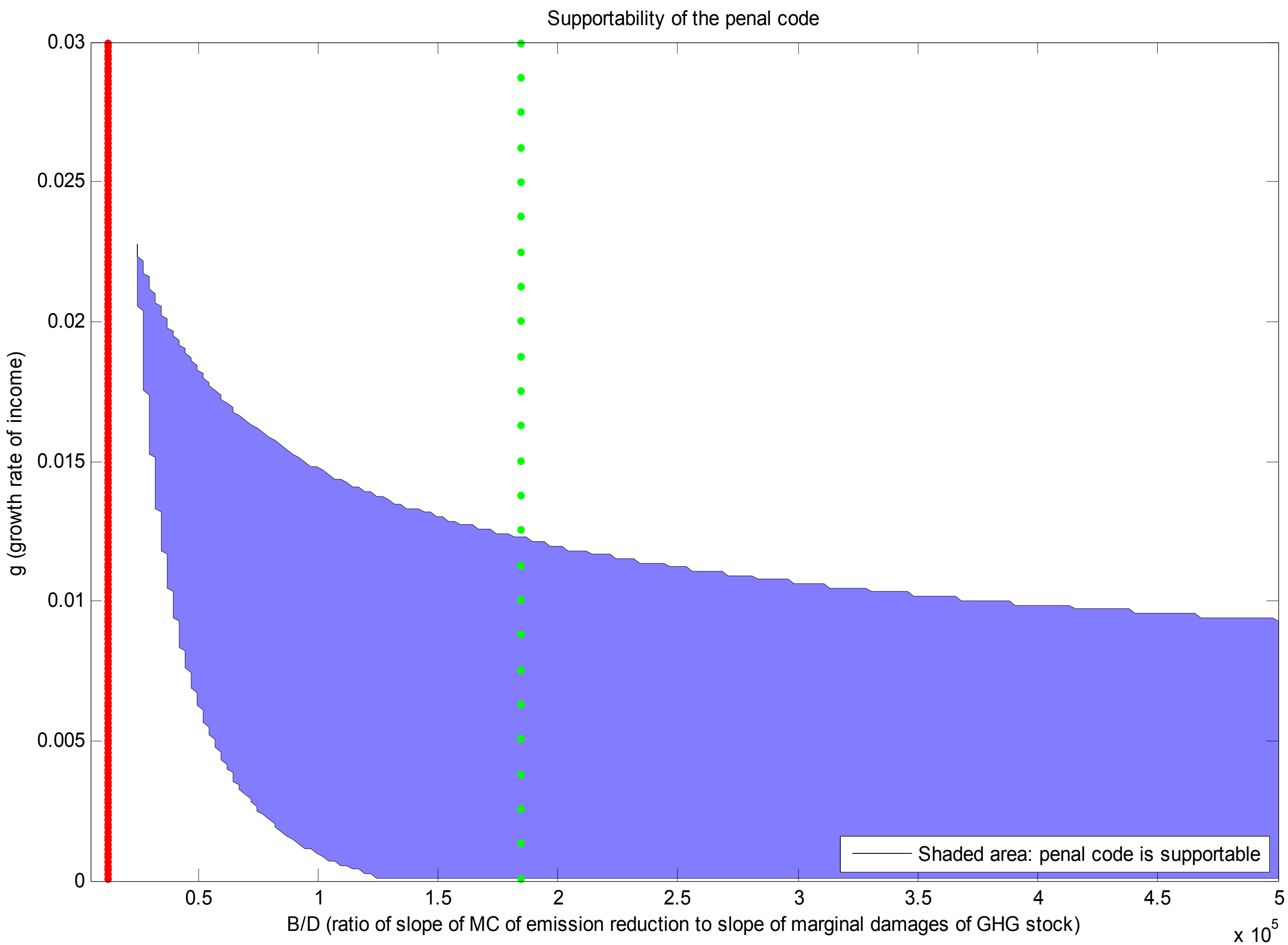
- Role of T (length of punishment phase)
  - With T > 1 can support SPE at smaller values of δ
- Role of N
  - Increasing N lowers all payoffs, changes opt. social path
  - Lowers gains from defection faster than from cooperation
- Expand analysis to allow for asymmetries
  - Calculate cutoff value of δ for each j, call it δ_j
  - SPE if $\delta \geq$ **max** $\{\delta_1, \ldots \delta_N\}$
- Discount factor embodies pop. & inc. growth (n, g), elast'y of MU (θ), social rate of time preference (ρ)

$$\delta = (1 + n + g)/(1 + \rho + g\theta)$$

SPE Penal code: role of n, g, θ
g vs. B/D ($n = 0$, $\theta = 2$)

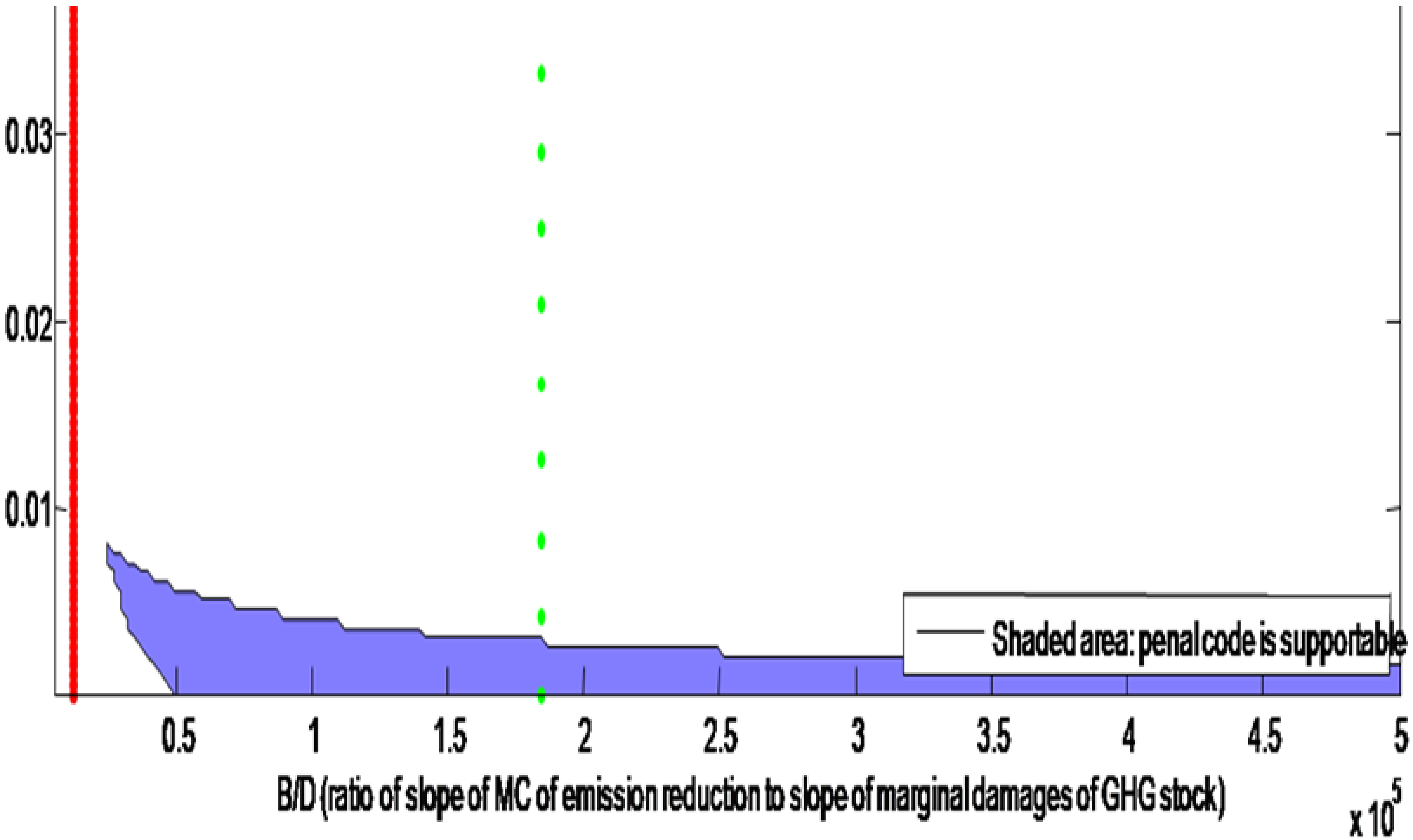


SPE Penal code: role of n, g, θ
g vs. B/D ($n = 0.006$, $\theta = 2$)



SPE Penal code: role of n, g, θ

g vs. B/D (n = 0, θ = 3)



Heterogeneous countries

	Reward function parameters				Discount factor δ (discount rate)					
Country	a_i	b_i	d_i		.9756 (2.5%)	.9709 (3%)	.9625 (3.9%)	.9615 (4%)	.9434 (6%)	.9091 (10%)
1	High	Low	Low		Y	NL	N	N	N	N
2	High	High	Low		Y	NL	N	N	N	N
3	Low	Low	Low		Y	Y	NH	N	N	N
4	Low	High	Low		Y	Y	NH	N	N	N
5	High	Low	High		Y	Y	Y	Y	NL	NL
6	High	High	High		Y	Y	Y	Y	NL	NL
7	Low	Low	High		Y	Y	Y	Y	Y	NL
8	Low	High	High		Y	Y	Y	Y	Y	NL

Heterogeneous countries

- a = 10.2 (H) or 10.0 (L)
- b = 5.0001 (H) or 5.0000 (L)
- d = .00002 (H) or .000025 (L)

λ = .99; z = 0; punishers emit at MBAU level

δ = 1/1.1 1/1.025