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Optimal Dynamic Fisheries Enforcement

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Introduction

Fisheries management consists of:

(i) A fisheries management system (a set of rules)
(ii) The enforcement of these rules

Within a given fisheries management system

The actual fisheries management is fisheries enforcement!!

So, a sensible fisheries policy needs to pay great attention to fisheries enforcement

Basic enforcement model

Private benefits of fishing: $B(q,x)$

Social benefits of fishing: $B(q,x)+\lambda\cdot(G(x)-q)$

Shadow value of biomass

The Enforcement Sector:

Enforcement effort: e — Endogenous (control)

Cost of enforcement: $C(e)$

Penalty level: f — Exogenous

Announced target: q^* — Exogenous

The penalty function

$$F(f,q-q^*)$$

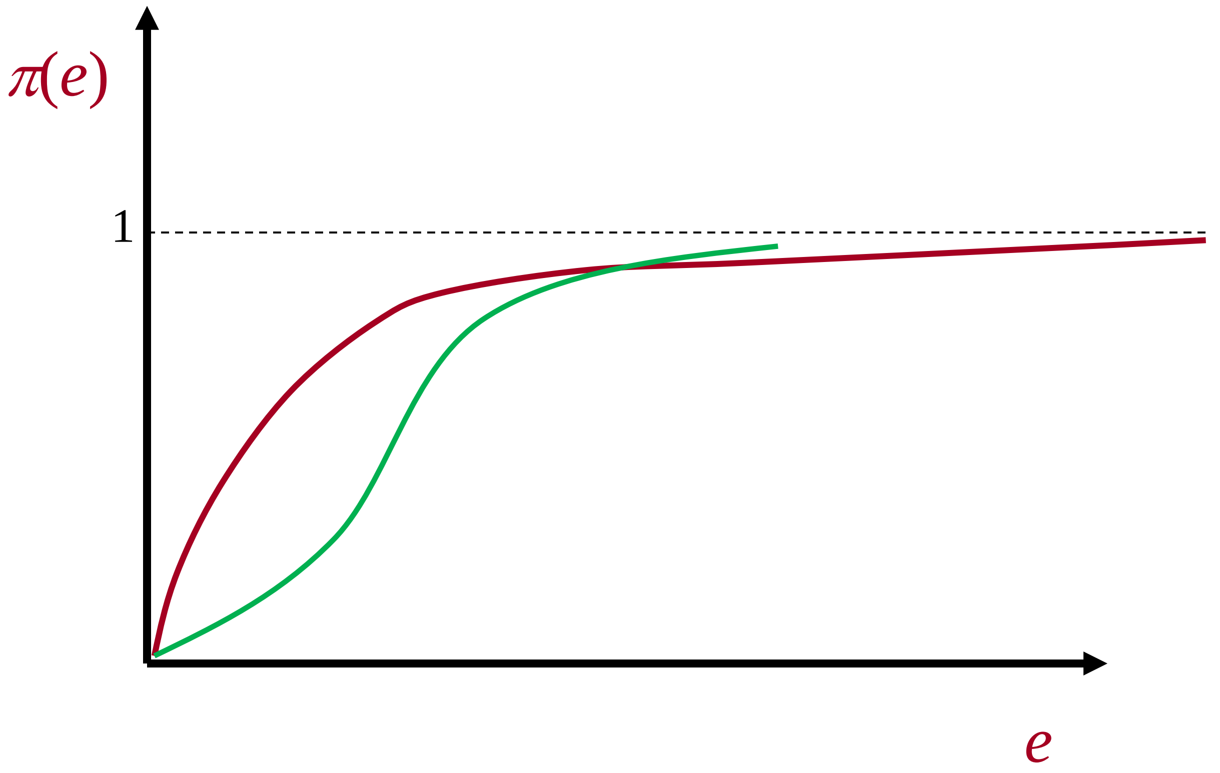
$$F(f,q-q^*) \geq 0,$$

$$F(0,q-q^*) = F(f,0) = 0,$$

$$F_f \geq 0,\ F_2 \geq 0$$

Model (cont.)

Probability of penalty function (if violate): $\pi(e)$



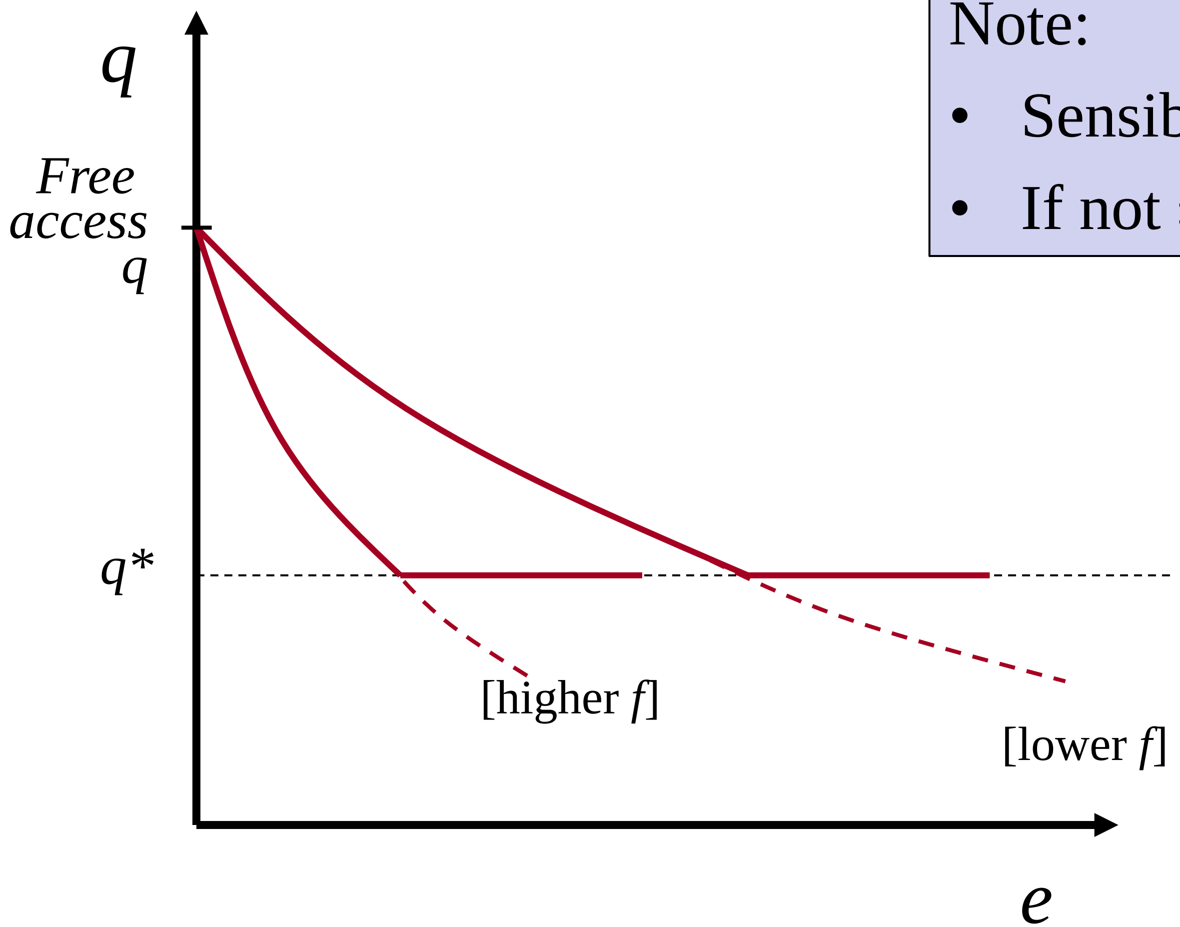
Private behaviour

Maximization problem: $Max\ B(q,x)-\pi(e)\cdot F(f,q-q^*)$

Necessary condition: $B_q(q,x)-\pi(e)\cdot F_2=0$

$\Rightarrow$ Enforcement response function: $q=Q(e,x,f,q^*)$

Enforcement response function



Note:

- Sensible $q > q^*$
- If not $\Rightarrow$ trouble

Socially optimal enforcement

The optimality problem

$$\underset{e}{Max}\ B(q,x)+\lambda\cdot(q-G(x))-C(e).$$

Subject to: $q=Q(e,x;f,q^*)$, ..etc.

$\Rightarrow$ Basic enforcement rule

$$(B_q-\lambda)=\frac{C_e}{Q_e}=\frac{\partial C}{\partial q}<0$$

Some implications

1. Traditional optimality condition: $B_q=\lambda$.

   Optimality with costly enforcement: $B_q<\lambda$

$\Rightarrow$ $q_{opt} > q^{\circ}$ (traditional optimality ignoring enforcement)

2. $q_{opt}>q^*$ (q^* is the announced *TAC*)

$\Rightarrow$ q^* is not the real target (for show only).

   Noncompliance is the desired outcome!

3. Ignoring enforcement costs can be very costly
   i. Wrong target harvest
   ii. Inefficient enforcement

Practical applications of the theory: Enforcement agency needs to know

1. The private benefit function of fishing, $B(q,x)$
2. The shadow value of biomass, λ
3. The enforcement cost function, $C(e)$
4. The penalty function, $\pi(e)$
5. The penalty structure, f

Note: Items 1 & 2 come out of a bio-economic model of the fishery.
Items 3, 4 and 5 are special enforcement data

Why dynamics?

- This theory is fine for the enforcement agency
  - Only needs to be informed of the current λ
- However, λ depends on future x (which depends on current enforcement)
- So, λ is endogenous**!!**
- Also, for longer term enforcement planning need the dynamic context

Optimal dynamic enforcement

$$\underset{\{e\}}{Max}\ V = \int_0^{\infty} \left[B(Q(e,x;f),x) - C(e) \right] \cdot e^{-r \cdot t} dt$$

Subject to $\dot{x} = G(x) - Q(e,x;f,q^*),$ ...etc.

Necessary conditions

(1) $(B_q(q,x)-\lambda)\cdot Q_e(e,x;f,q^*)=C_e(e),\ \forall\ t$

(2) $\dot{\lambda}-r\cdot\lambda=-B_q(q,x)\cdot Q_x(e,x;f,q^*)-B_x(q,x)$

$$-\lambda\cdot(G(x)-Q_x(e,x;f,q^*),\ \forall t$$

(3) $\dot{x}=G(x)-Q(e,x;f,q^*),\ \forall t$

(1) is the basic (static) social enforcement rule!!
(2) describes the optimal evolution of λ

Optimal equilibrium

Costly enforcement

$$\lambda = \frac{B_x + B_q \cdot Q_x}{r - G_x + Q_x}$$

$$G_x + \frac{C_e \cdot Q_x + B_x \cdot Q_e}{B_q \cdot Q_e - C_e} = r$$

No or costless enforcement

$$\lambda = \frac{B_x}{r - G_x}$$

$$G_x + \frac{B_x}{B_q} = r$$

So, enforcement modifies the marginal stock effect, Γ

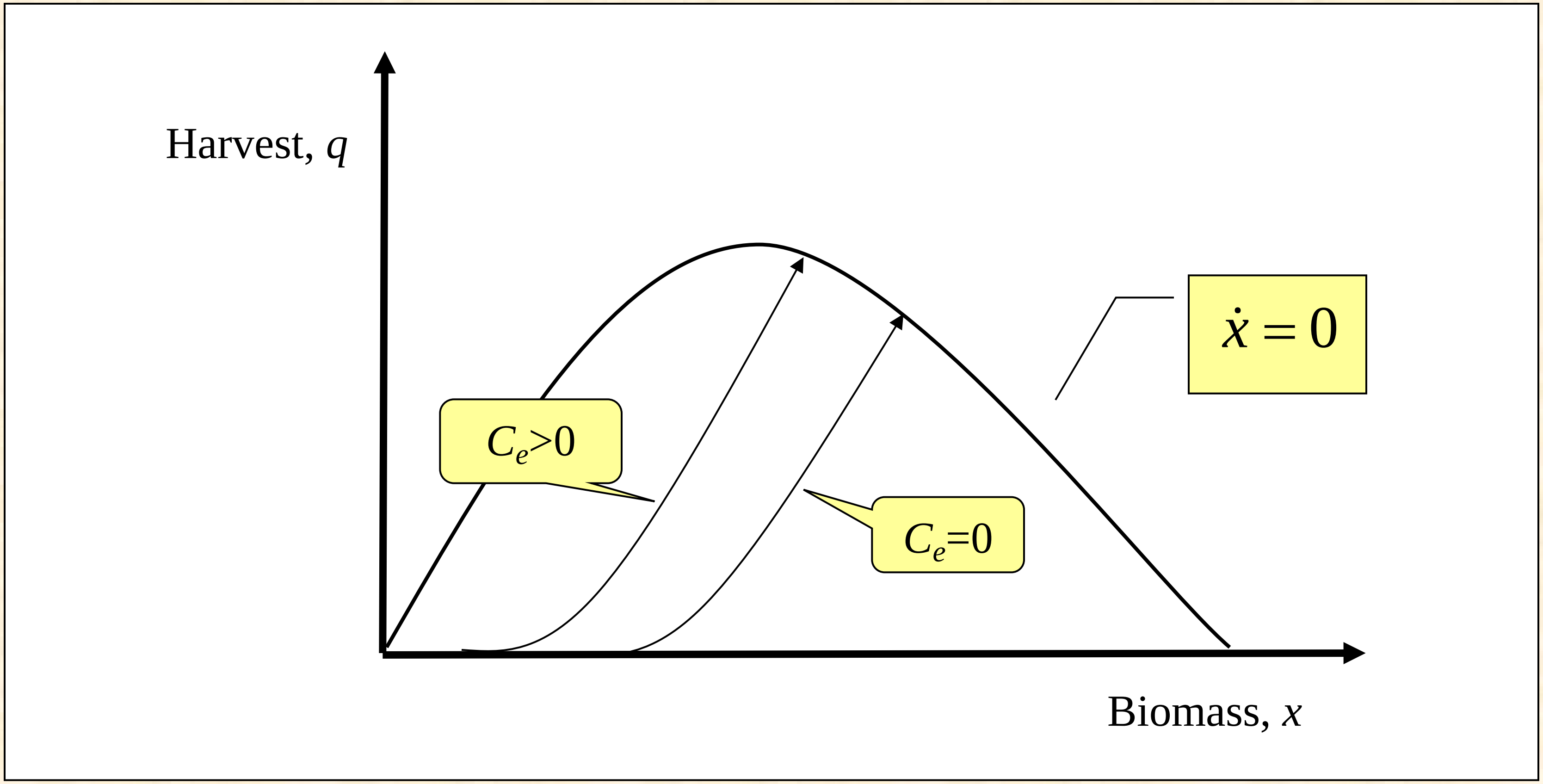
- In traditional fisheries models, $\Gamma>0$
- Under costly enforcement, Γ can be of any sign
- However, likely that $\partial\Gamma / \partial C_e < 0$

$\Rightarrow$Thus Γ(enforcement)<Γ(costless enforcement)

- x (enforcement) < x (costless enforcement)

Optimal feed-back rules

Can show that $q_{opt}(x) \geq q°(x)$!



Numerical example

$$p \cdot q - c \cdot \frac{q^2}{x} - FK - f \cdot \pi(e) \cdot q$$

$$Q(e,x,f) = \frac{(p - f \cdot \pi(e)) \cdot x}{2 \cdot c}$$

$$\pi(e) = \frac{e}{\eta + e}$$

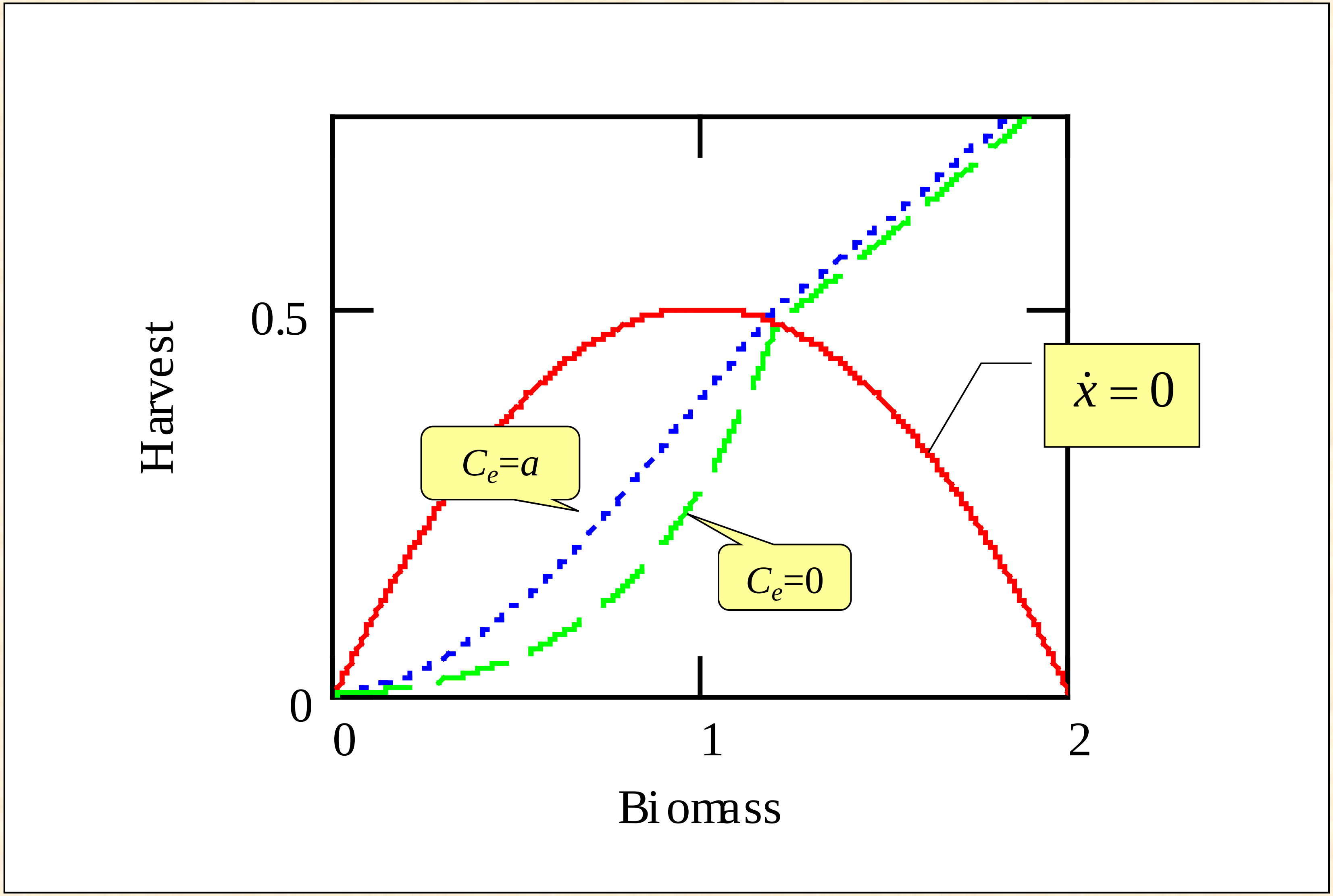
$$C(e) = a \cdot e$$

$$x_{t+1} = x_t + \alpha \cdot x_t - \beta \cdot x_t^2 - q_t$$

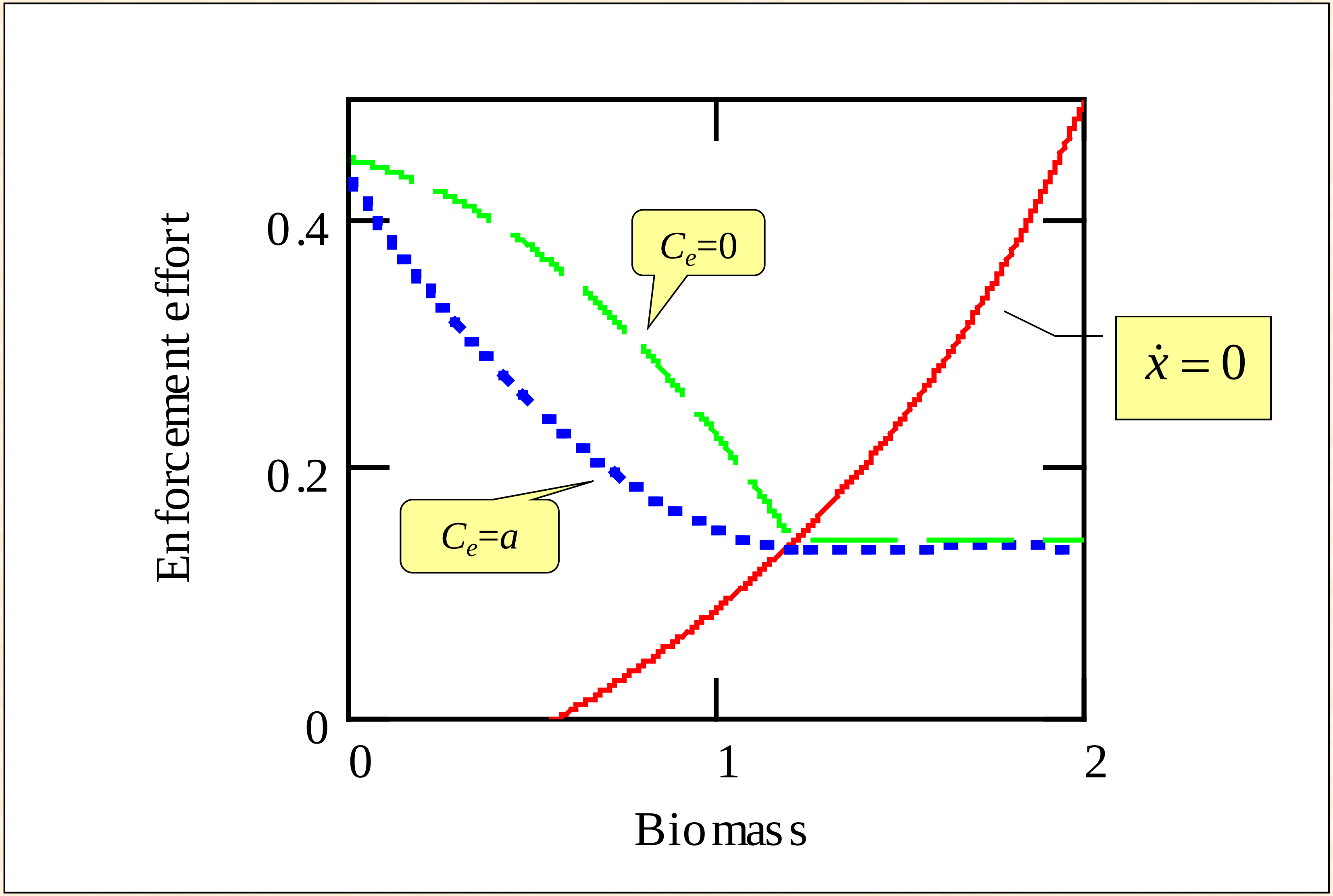
Parameters

α	1
β	0.5
p	1
f	2
a	0.1
η	0.5
c	0.7
r	0.05
FK	0.1

Optimal Paths
(harvest-biomass space)



Optimal Paths
(enforcement effort-biomass space)



Note

- Optimal enforcement depends on biomass
  - Important practical implications for set-up and operations of enforcement agencies
- Optimal enforcement is high at low biomass levels (high λ) and vice versa
- High enforcement costs may render enforcement and, therefore, fisheries management uneconomical

Enforcement by adjusting *f* or *q**

- Can probably adjust *f* and *q** at no or very low cost

$\Rightarrow$ Economically preferable

- If enforcement is costless $\Rightarrow$ $q_{opt} = q°(x)$

In that case optimal feed-back rules for *f* and *q** are implicitly defined by

$$q°(x) = Q(e,x;f,q^*).$$

Can show

$$\frac{\partial f}{\partial x} < 0$$

$$\frac{\partial q^*}{\partial x} > 0$$

$$q^*(x) < q_{opt}(x)$$

END

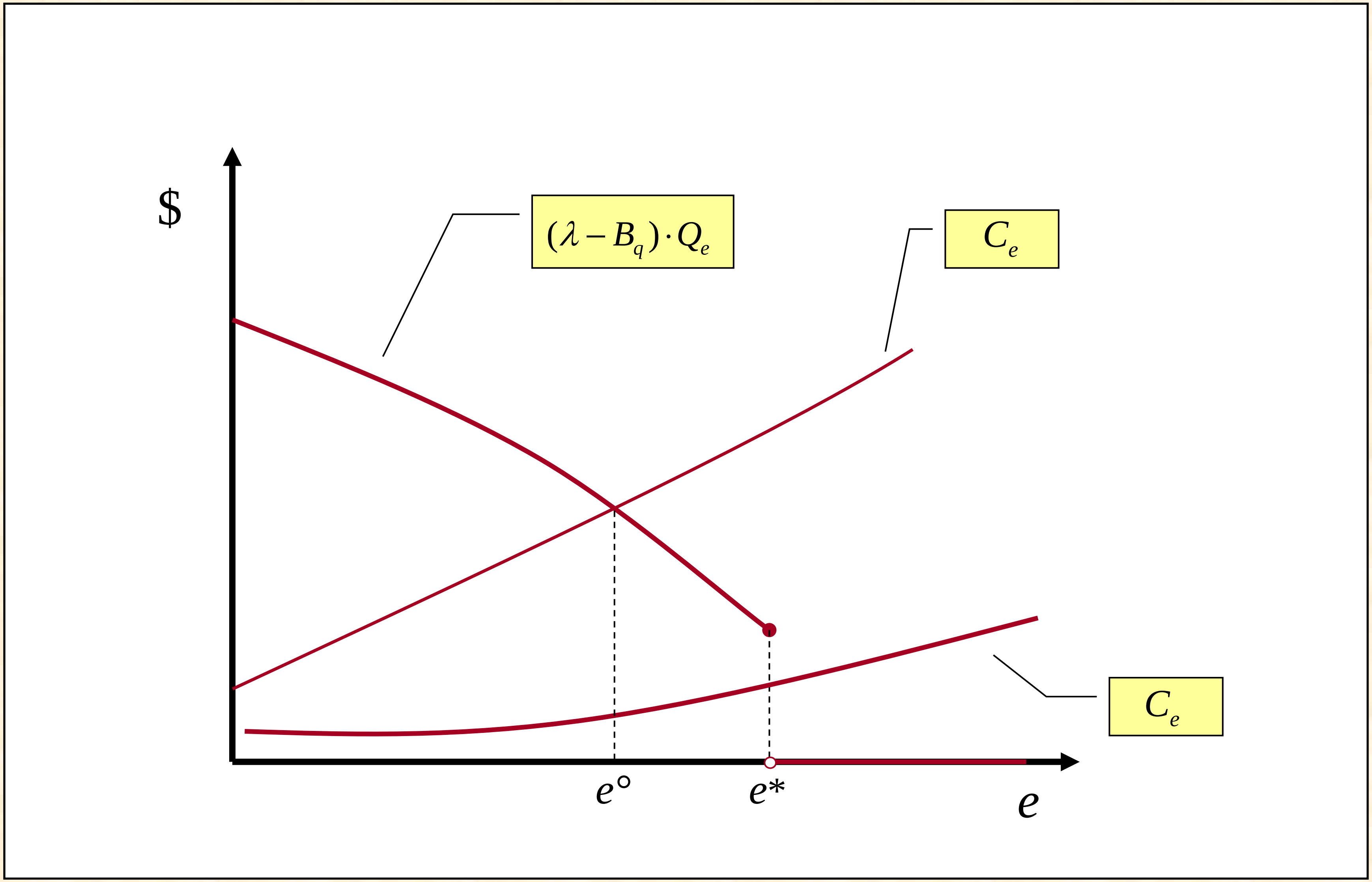
Numerical results
The whole program

Present value of program (social):	4.145
Private value of program:	0.553
Private and social value of no enforcement:	2.409
Present value of fines:	3.878
Present value of enforcement costs:	0.286

Numerical results
Equilibrium

Social benefits:	0.242
Private benefits:	0.046
Fines:	0.210
Enforcement costs:	0.013
Enforcement costs/revenues:	0.026

Social optimality: Illustration



To apply theory: Empirical requirements

1. The private benefit function of fishing, $B(q,x)$
2. The shadow value of biomass, λ
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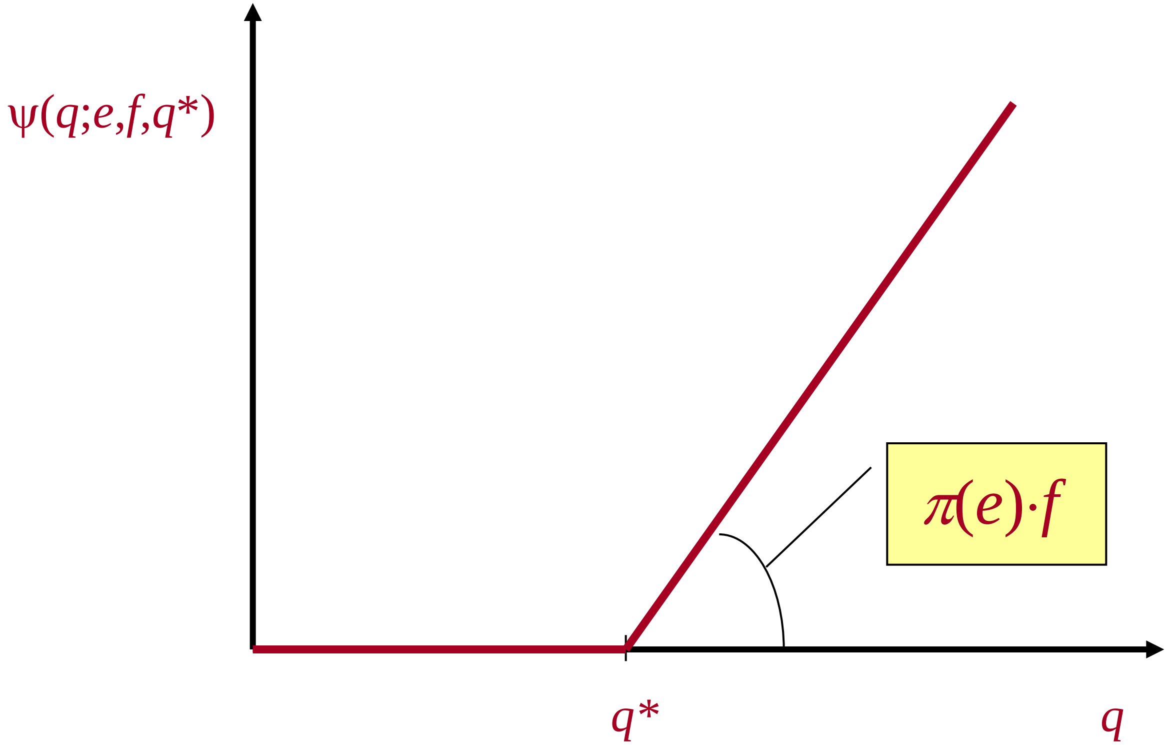
Model (cont.)

Private costs of violations: $\psi(q;e,f,q^*) = \pi(e)\cdot f\cdot(q-q^*)$, if $q \geq q^*$

$\psi(q;e,f,q^*) = 0$, if $q < q^*$



Model (cont.)

Private benefits under enforcement

$B(q,x) - \pi(e) \cdot f \cdot (q - q^*),\ q \geq q^*$

$B(q,x)$, otherwise

Social benefits with costly enforcement:

$B(q,x) - \lambda \cdot q - C(e)$

The discontinuity problem

- Analytically merely cumbersome
- Practically troublesome
  - Stop getting responses to enforcement alterations
- To avoid the problem
  - Set q^* low enough (lower than the real target)
  - Aim for the appropriate level of noncompliance
- A well chosen q^* is not supposed to be reached ($\Rightarrow$ Non-compliance is a good sign!)