Managing Imperfectly Observed Complex Systems

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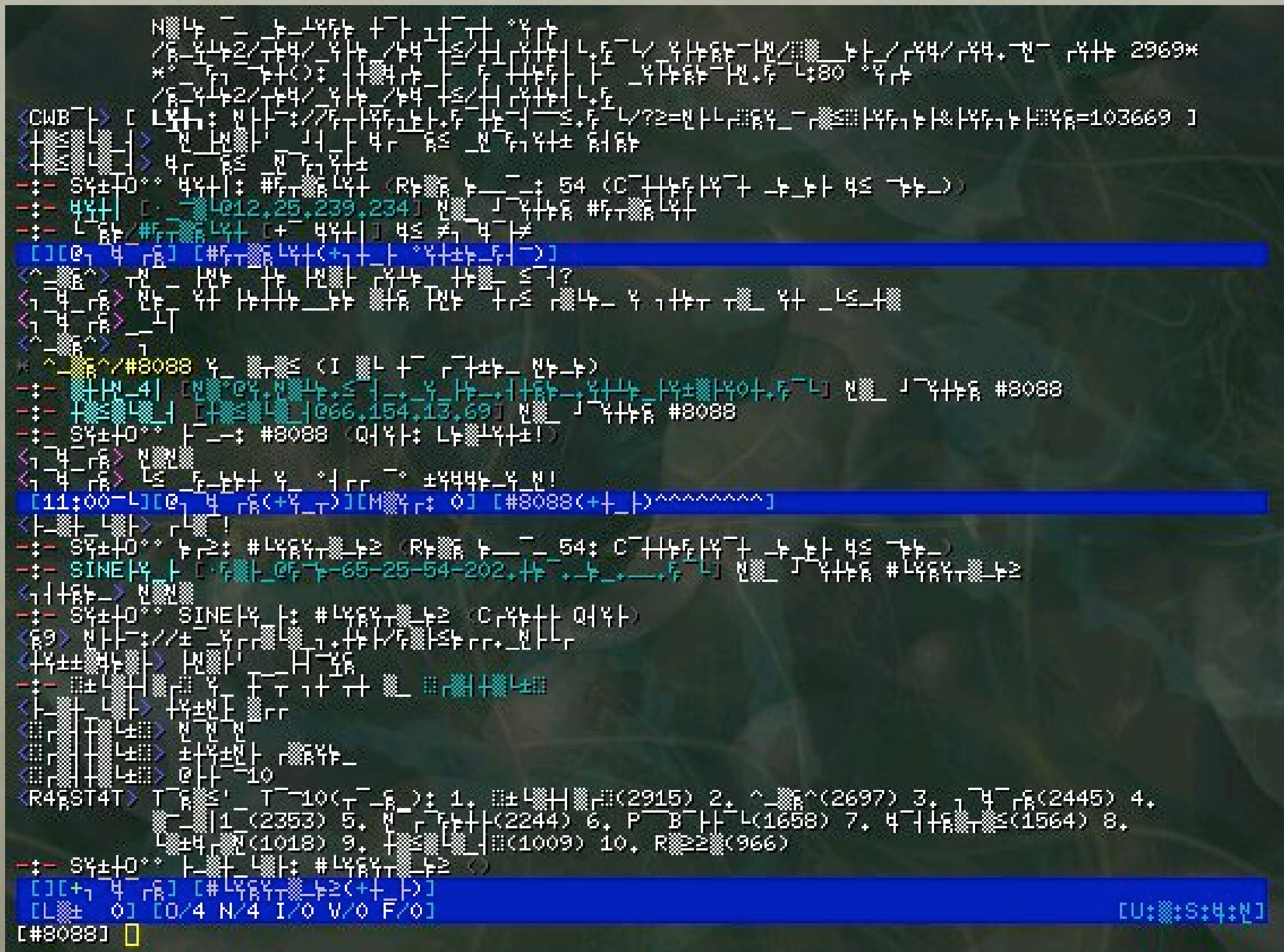
TALK OUTLINE

- Motivation
- Roughgarden & Smith's claim
- Optimal policy descriptions
- Critique of Roughgarden & Smith
- Our Model
- Results
- Conclusions

enfish.c?



THE REAL `enfish.c`

enfish.c.txt

```
tmax = 50; runtot = 100; nscanstep = .05;

daymax = 365 * tau; interest = exp(rho*tau);

seed = (long) time((time_t *) NULL); fishseed(seed);

for (ntarg = ko*nscanstep; ntarg < 1000; ntarg += nscanstep*ko)
  {
  nsum = 0; nsqsum = 0; catchsum = 0; catchsqsum = 0; steps_not_extinct = 0;
  assetssum = 0; assetssqsum = 0; nextinct = 0; textinctsum = 0;
  textinctsqsum = 0; htarg = ro*ntarg*(ko - ntarg)/ko; ftarg = ro*(ko - ntarg)/ko;

  for (run = 1; run <= runtot; ++run)
    {
    account = ko - ntarg; nt = nt_tau = ntarg; textinct = 0;
    fishtime = 0; ht = 0; rt = ro; kt = ko;

    for (fishtime = 1; fishtime <= tmax; ++fishtime)
      {
      // z = zt();
      // printf("%lf\n",z);
      rt = (1 + rksd*zt())*ro; kt = (1 + rksd*zt())*ko;
      nte = (1 + nse*zt())*nt_tau; tact = ftarg*nte*tau;
      ht = (1 + hse*z)*tact/tau; ntday = nt;
      for (day = 0; day < daymax; ++day)
        {
        ntday += (rt*ntday*(kt - ntday)/ko - ht)*(tau/daymax);
        if (ntday <= 0)
          {
          ntday = 0;
          break;
          }
```

MOTIVATION

- Fishery collapse has emerged as a widespread phenomenon
- Many possible causal factors
  - Overcapitalization of the industry
  - Politicized catch quotas
  - Imperfect monitoring and enforcement
  - Increased stochasticity

Why Fisheries Collapse …

- Roughgarden and Smith (1996) assume multiple sources of stochasticity and find that the use of the "economic" criterion leads to fishery collapse

"Economic theory for managing a renewable resource, such as a fishery, leads to an ecologically unstable equilibrium as difficult to maintain as balancing a marble on top of a dome. A fishery should be managed for ecological stability instead – in the analogy, as easy to maintain as keeping a marble near the base of a bowl".

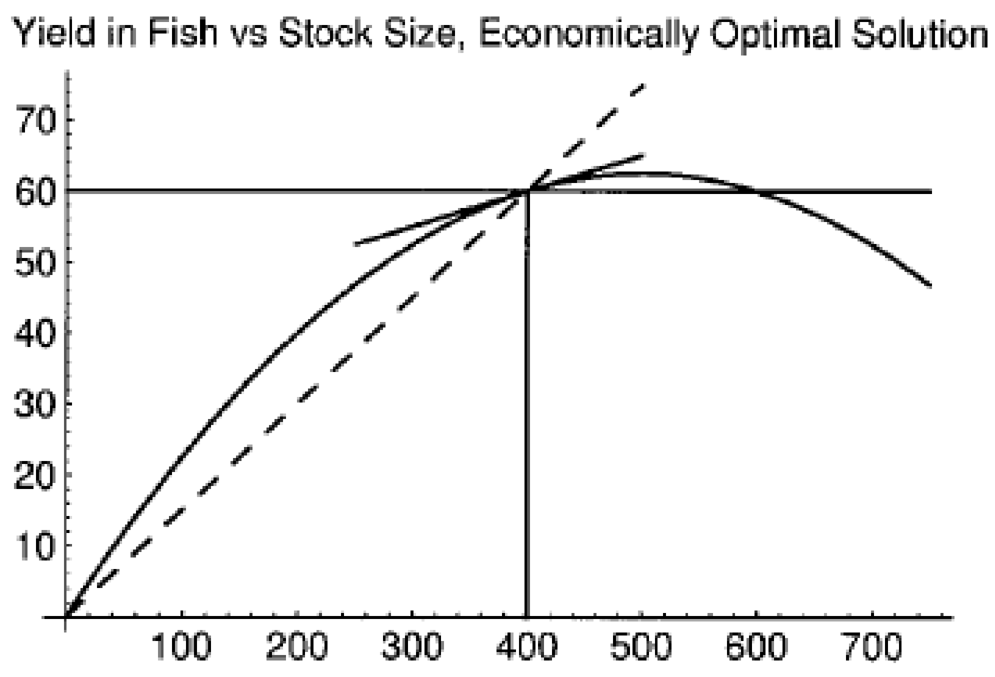
DETERMINISTIC MODEL

- The manager seeks to maximize the present discounted sum of profits, subject to the growth equation:

$$\max_{h(t)} \int_0^\infty e^{-rt} p h(t) \quad s.t. \quad \dot{x}(t) = g(x(t)) - h(t)$$

where r is the discount rate, p is the price of fish, h is the harvest, g is the stock-recruit function, and x is the stock of fish

DETERMINISTIC SOLUTION

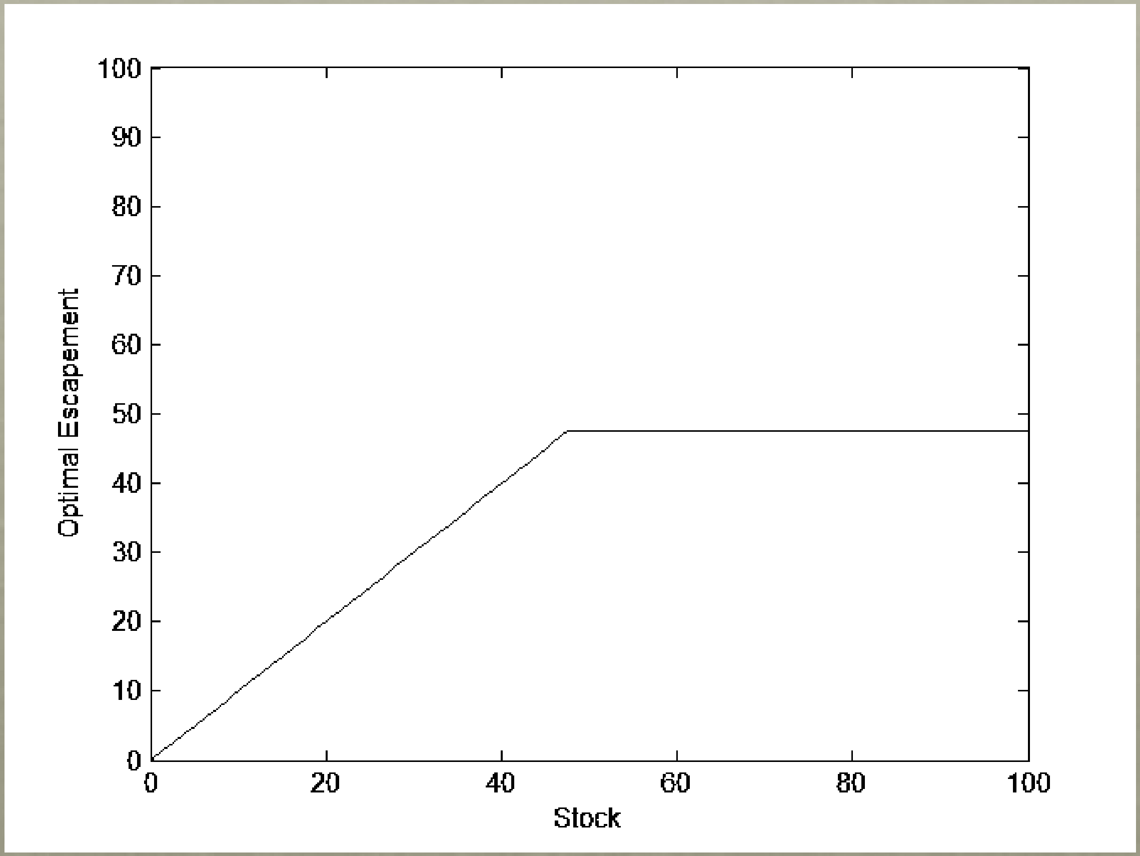


In this example, optimal target stock equals 400 and annual catch equals 60.

- What is the intuition behind this result?
- What are its properties in terms of stock dynamics?

ALTERNATIVE REPRESENTATION

The solution to the deterministic model is given by $$g'(x^*) = r$$

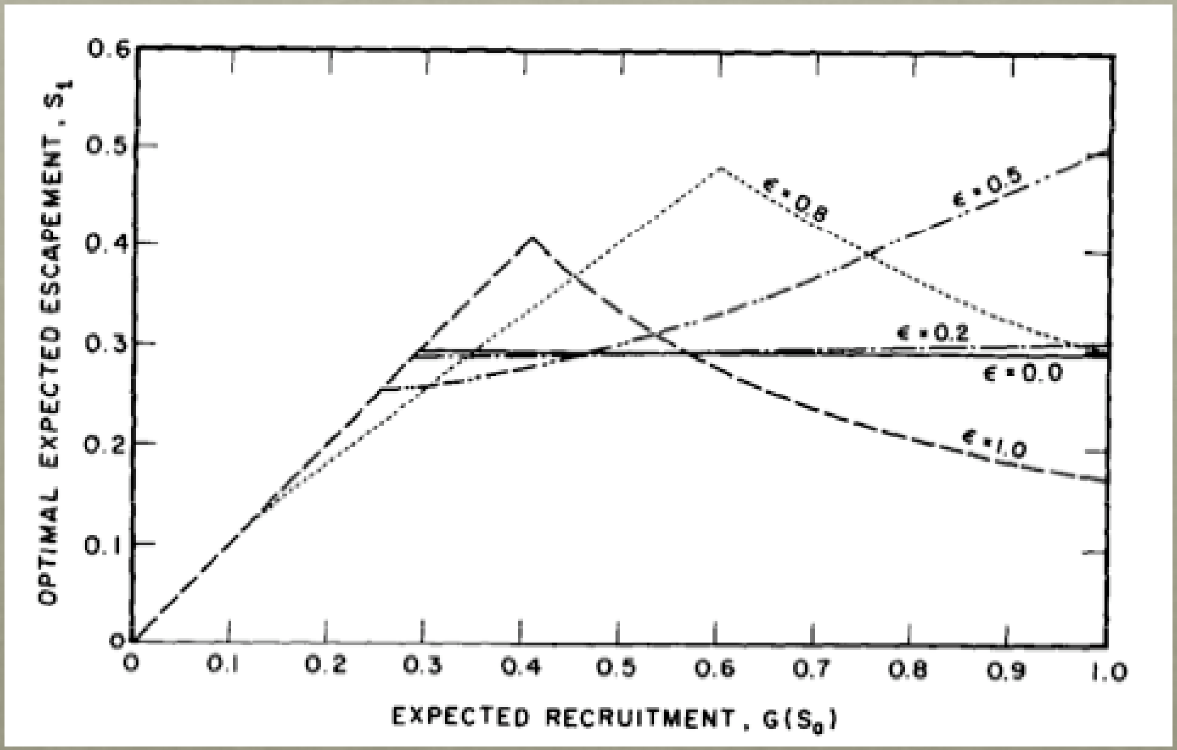


Future Stock Uncertainty

- Reed (1979) assumes manager can observe stock accurately at the time of announcing catch quota but is faced with recruitment uncertainty
- He shows that the solution to this problem is qualitatively similar
- Recruitment uncertainty leads to higher escapement

CURRENT STOCK UNCERTAINTY

- Clark and Kirkwood (1986) assume manager observes pre-spawning stock accurately and post-spawning stock with noise



Multiple Uncertainty

- Roughgarden and Smith pose a new problem: What is the implication of following the solution of deterministic economic model when
  - The stock-recruit relationship is stochastic,
  - Stock measurements are prone to errors, and
  - Actual take is prone to error?
- To answer this question, the authors run simulations and find that following the deterministic economic decision rule leads to …

… DISASTER!

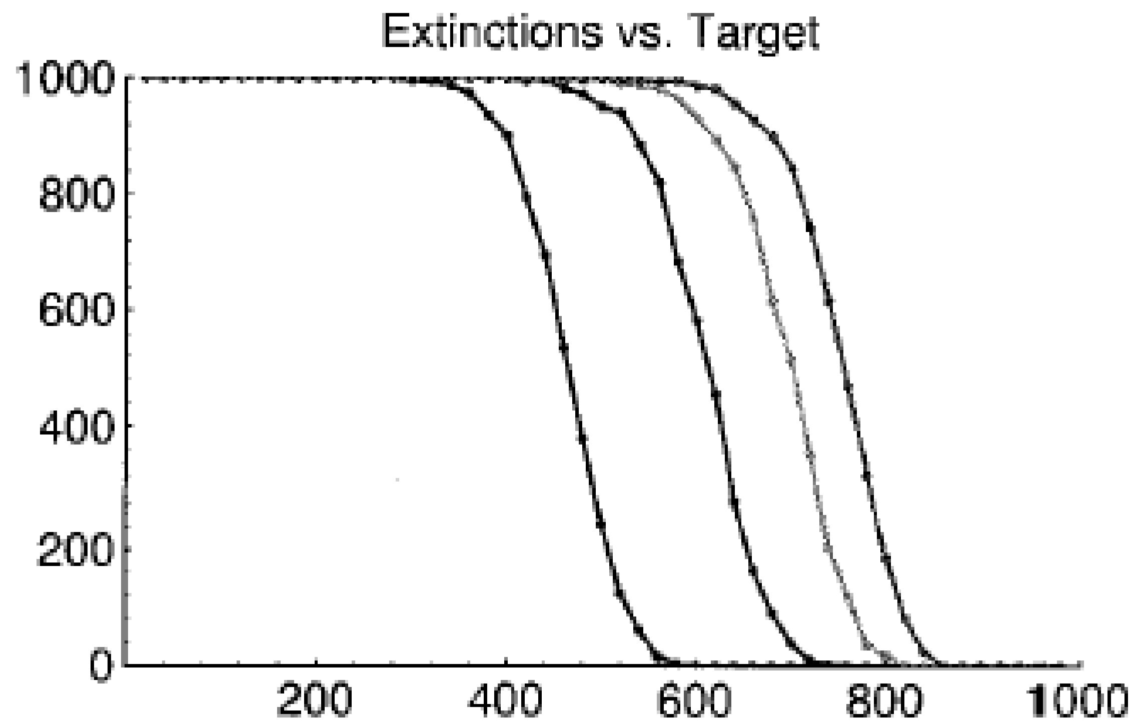
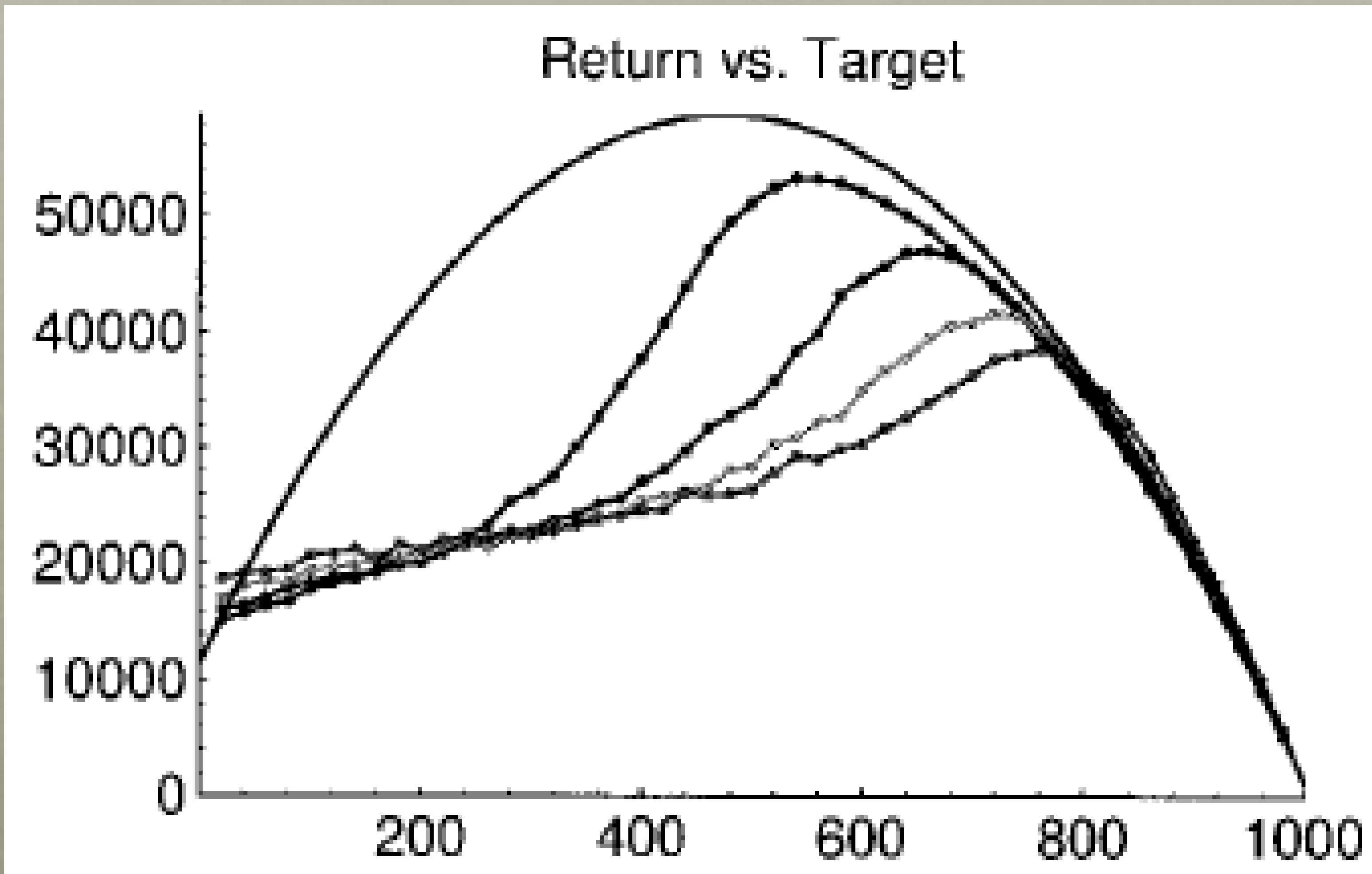
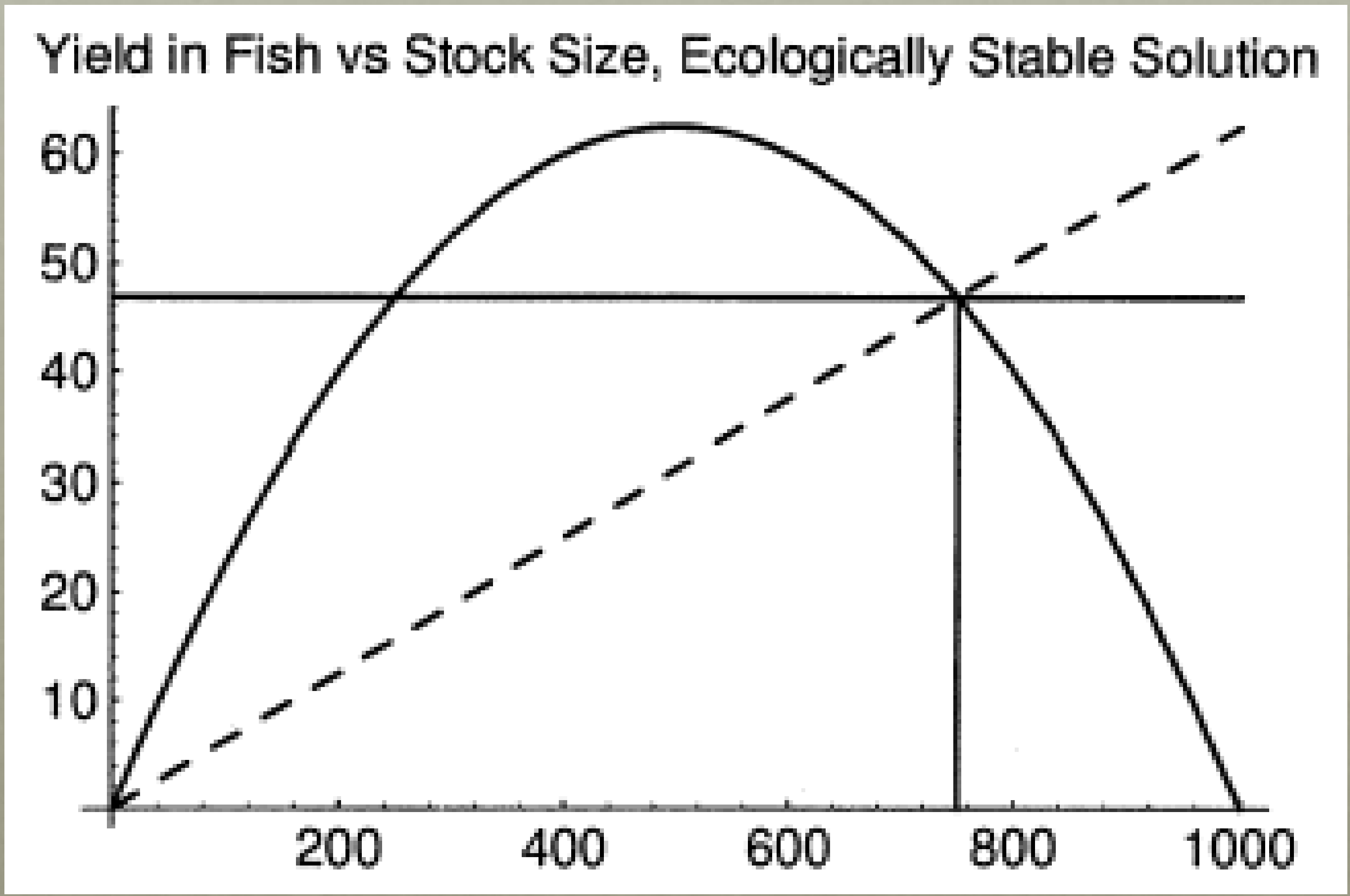


FIG. 5. Risk of fishery collapse over 50 years, measured as the number of simulations where the stock became extinct, as a function of stock size. Curves from left to right are for σ of 0.2, 0.4, 0.6, and 0.8.

R&S OPTIMAL POLICY



R&S RECOMMENDATION



OUR WORK

- The deterministic policy recommendation from the economic model is inapplicable to the highly stochastic world the authors create.
- The 3/4th K solution is a constrained optimum i.e. it is the optimum solution *within the class of constant-escapement rules*.
- This raises two questions:
  - What *is* the optimum solution under three sources of uncertainty mentioned above?
  - How does the optimum solution compare with Roughgarden and Smith's solution?

Assumptions

- Each of the shocks is multiplicative and is drawn from known independent uniform densities.
- The stock-recruit relationship is logistic with known parameters.
- The only state variable used by the manager is current period measurement. The control variable is the seasonal catch quota.
- “Small” and “large” uncertainty refer to uniform shocks of $\pm$10% and $\pm$50% around the mean values.

Problem Formulation

- The manager's problem is to

$$\max_{\{q_t\}\geq 0} \mathbb{E}\left\{\sum_{0}^{\infty} \alpha^t h_t\right\}$$

$$x_t = z_t^g G(s_{t-1})$$
$$s_t = x_t - h_t$$
$$m_t = z_t^m x_t$$
$$h_t = \min(x_t, a_t)$$

SOLUTION ALGORITHM

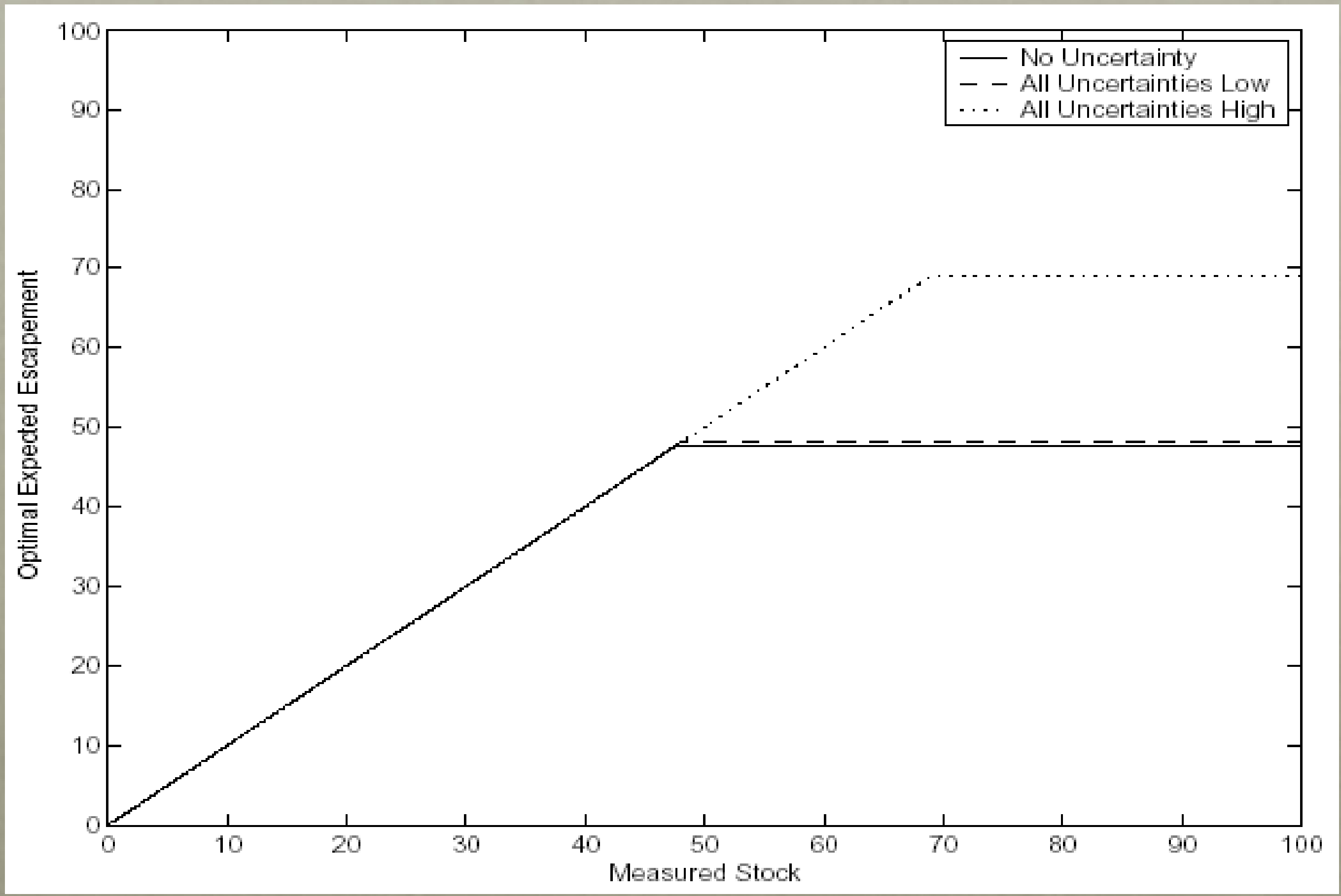
- The DPE of this problem is

$$J_t(m_t) = \max_{q_t \geq 0} \mathbb{E}_{x_t,h_t} \left\{ h_t + \alpha J_{t+1} \left(z^m_{t+1} z^g_{t+1} G(x_t - h_t) \right) \right\}$$

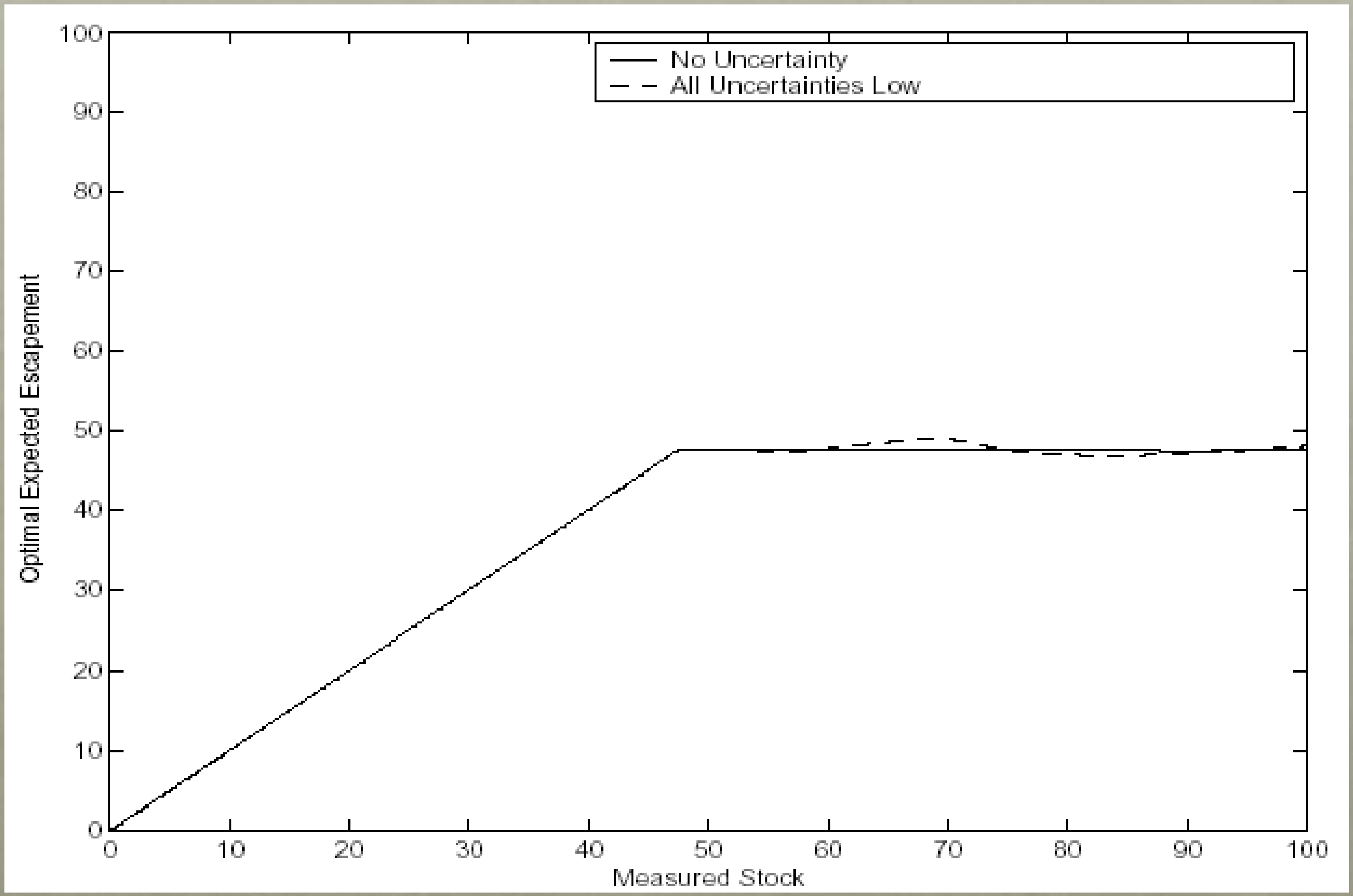
We solve this dynamic problem using value function iteration, which involves

- making a guess of the value function,
- finding the conditional solution,
- recomputing the value function, and
- checking for convergence.

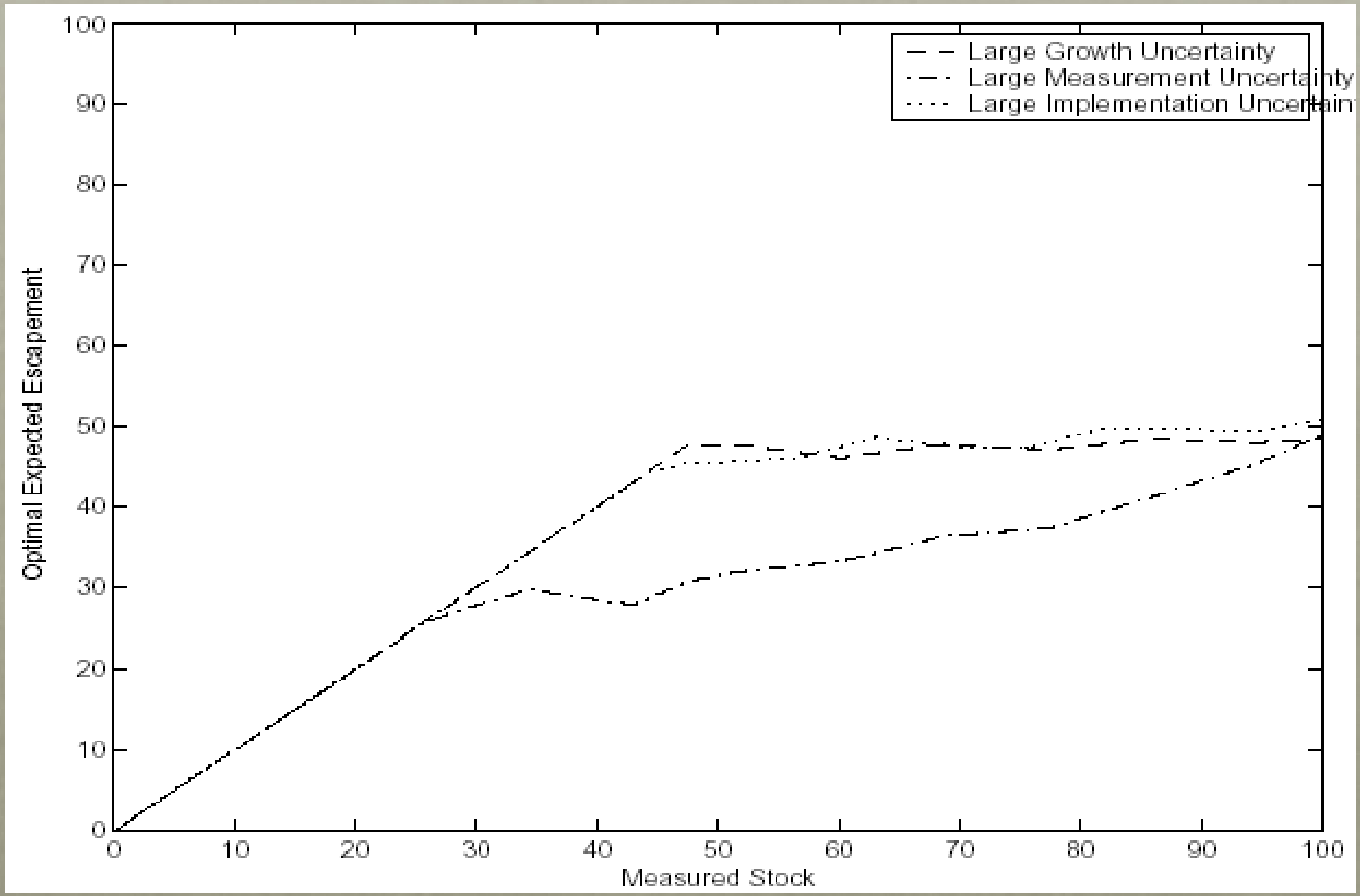
Results: Recruitment Uncertainty



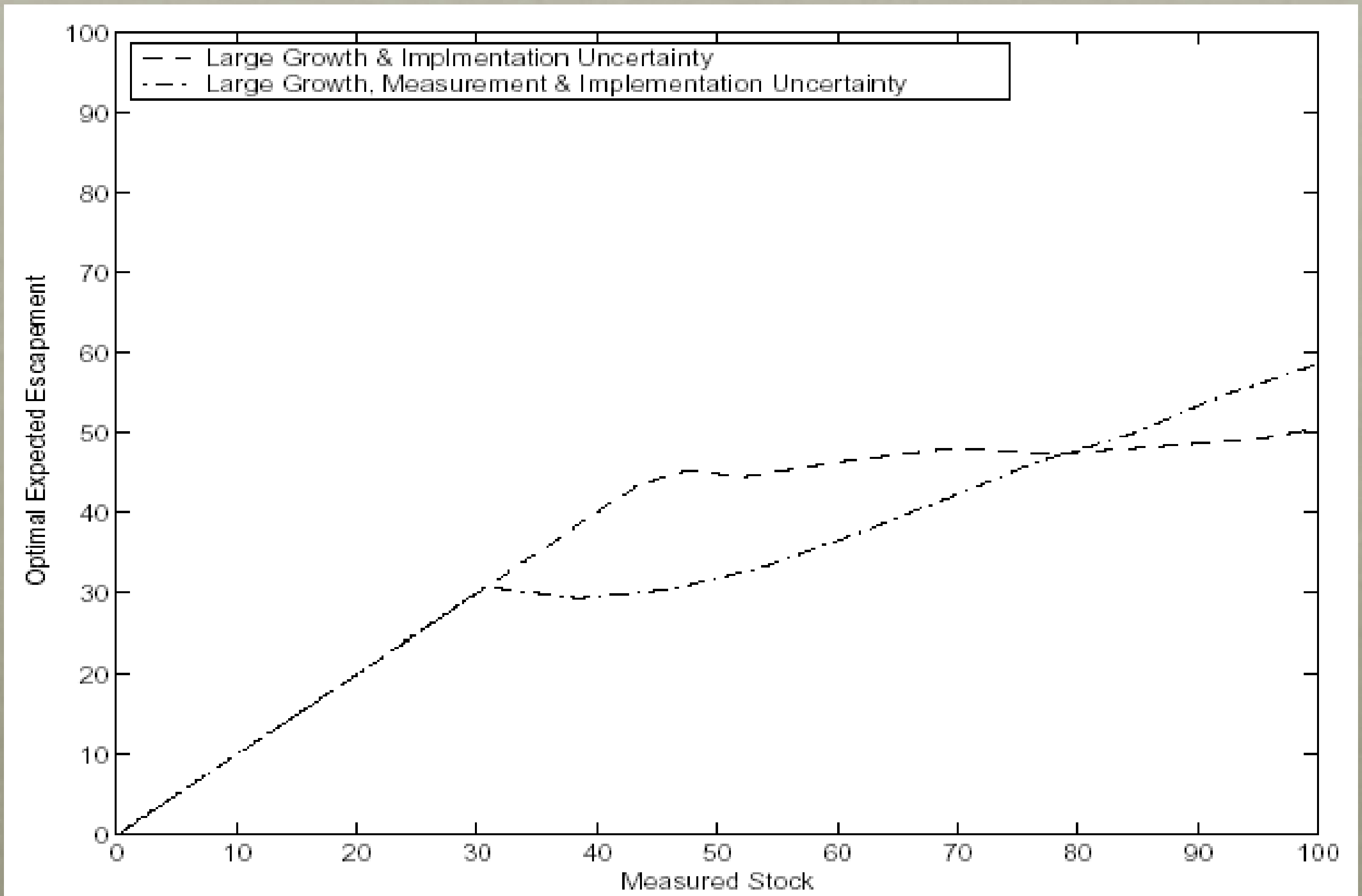
Results: Small Multiple Uncertainty



Results: One Large Uncertainty



Results: Multiple Uncertainty



Sensitivity Analysis

- To see how robust our results are to the assumptions we make, we conduct sensitivity analyses with respect to:
  - The stock-recruit relationship,
  - The value of the intrinsic growth parameter, and
  - Search costs
- We find that our results are fairly robust with respect to each of these

SUMMARY STATISTICS

Policy	Extinction Probability Within 50 Years	Mean Extinction Time (Years)	Commercial Value Over 50 Years (Dollars)
All Small Shocks (Optimal Policy)	0.00	∞	506
All Small Shocks (Constant-Escapement Policy)	0.00	∞	506
Large Growth Shock (Optimal Policy)	0.00	∞	501
Large Measurement Shock (Optimal Policy)	0.00	∞	433
Large Implementation Shock (Optimal Policy)	0.00	∞	494
All Large Shocks (Optimal Policy)	0.06	890	421
All Large Shocks (Constant-Escapement Policy)	0.57	60	308

CONCLUSIONS

- Given our assumptions, we find that the optimal policy is does better than the constant-escapement policy on *both* counts: commercial profitability as well as extinction probability
- However, we make a number of simplifying assumptions in this model, which makes it inapplicable
- In light of this, we see this model as an initial step towards the development of more complex and realistic models

THANK YOU!