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Advances in Fisheries Modelling

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Topics

I. Fisheries modelling in a wide perspective
   - The social purpose of fisheries modelling
   - The historical development of fisheries modelling
   - What are the pressing modelling tasks?

II. Specific topics
   - General equilibrium fisheries modelling
   - Computable optimal feed-back paths


Fisheries modelling:
A broad perspective

Social purpose of fisheries modelling

Assist in solving the social problem of inefficient use of fish (aquatic) resources

Note:

- By no means self-evident (or uncontroversial)
- Represents the pragmatic (practical) approach to science
- In direct contradiction to the "pure science" approach

⇒ Wide-reaching implications for fisheries modelling!

Social purpose ..... cont.

Fisheries modelling should be practically oriented

- In the sense of contributing to improved real-life fisheries
- But not necessarily non-technical or simple

The fisheries problem

$$\underset{\{\boldsymbol{y}\}}{Max} \int_0^{\infty} W(\boldsymbol{y}, \boldsymbol{p}; \boldsymbol{x}; \boldsymbol{z}) \cdot e^{-r \cdot t} dt$$

$$\text{s.t.} \quad \dot{\boldsymbol{x}} = \boldsymbol{G}(\boldsymbol{x}, \boldsymbol{z}, \boldsymbol{y})$$

W(.,.;.;.): Social welfare function (≈indirect utility function, includes different uses of marine resources)

y: Vector of <u>all</u> fisheries actions (not only harvests)

p: Vector of economy prices (for G.E. considerations)

x: Vector of <u>all</u> aquatic resources (not only fish stocks)

z: Vector of exogenous variables

This is the problem we would like to solve

Evolution of fisheries modelling

	Modelling class	Emerging
1.	Biological modelling:	1900
2.	Fisheries profit function:	1950s
3.	Bioeconomic models:	1960s
4.	Management models:	1980s
5.	Fisheries enforcement models:	2000s
6.	Comprehensive fisheries models:	not yet
7.	Comprehensive marine resource use:	not yet
8.	Integrated general equilibrium models:	not yet

Biological Modelling

- The study of $\dot{\boldsymbol{x}} = \boldsymbol{G}(\boldsymbol{x}, \boldsymbol{z}, \boldsymbol{y})$
  - Multi-species, ecosystems
  - Totally technical – no human component
  - No economics whatsoever!!
- Totally dominant in fisheres research globally
  - Iceland 98% of all public funds for fisheries research

Fisheries profit function

- The study of $\pi = \Pi(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z})$
- Components
  - Harvesting function: $\boldsymbol{q} = \boldsymbol{Y}(\boldsymbol{e}, \boldsymbol{x}, \boldsymbol{z}),\ \boldsymbol{q} \subset \boldsymbol{y},\ \boldsymbol{e} \subset \boldsymbol{y}$
  - Harvesting cost function: $C(\boldsymbol{e}, \boldsymbol{z})$
  - Price function: $\boldsymbol{P}(\boldsymbol{q}; \boldsymbol{z})$
- Largely technical (production theory) – very little human behaviour (primarily prices)

⇒Some (but limited) economics

- Studied since the mid 1950s

Bio-economic models

Construction and manipulation of the system:

$$\int_0^{\infty} \Pi(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}) \cdot e^{-r \cdot t} dt$$

$$\dot{\boldsymbol{x}} = \boldsymbol{G}(\boldsymbol{x}, \boldsymbol{z}, \boldsymbol{y})$$

- Combines biological and profit function models
- Adds computational manipulation
- Still very little human behaviour $\Rightarrow$ limited economics
- Emerged in the 1960s, expanded fast in the 1970s and 80s; still a very active field.

Management models

$$y = Y(x, z; \Omega)$$

Ω = management rules

$Y(x,z;\Omega)$ are human response functions $\Rightarrow$ economics

- Considerable research since 1980s
- Now broadly know which systems work and which do not

Management models cont.

Now the fisheries problem is seen as

$$\underset{\Omega}{Max} \int_0^{\infty} \Pi(\boldsymbol{x}, \boldsymbol{Y}(\boldsymbol{x}, \boldsymbol{z}, \Omega), \boldsymbol{z}) \cdot e^{-r \cdot t} dt$$

$$s.t. \ \dot{\boldsymbol{x}} = \boldsymbol{G}(\boldsymbol{x}, \boldsymbol{z}, \boldsymbol{Y}(\boldsymbol{x}, \boldsymbol{z}, \Omega))$$

So, the problem is to select/design the "best" fisheries management system

Fisheries Enforcement Modelling

A fisheries management system will <u>not</u> manage fisheries
Enforcement of the management rules is needed

Enforcement response: $\boldsymbol{y}=\boldsymbol{Y}(\boldsymbol{x},\boldsymbol{z},\Omega, \boldsymbol{a},\boldsymbol{f})$

Enforcement cost: $C(\boldsymbol{a},\boldsymbol{f})$

$\boldsymbol{a}$ = vector of enforcement efforts
$\boldsymbol{f}$ = vector of sanctions

- Research began in 2000
- Hardly any substantial results yet

Comprehensive Fisheries Models

Now the management problem is

$$\underset{\{\boldsymbol{a},\boldsymbol{f},\Omega\}}{Max} \int_0^\infty [\Pi(\boldsymbol{x},\boldsymbol{Y}(\boldsymbol{x},\boldsymbol{z},\Omega,\boldsymbol{a},\boldsymbol{f}),\boldsymbol{z}) - C(\boldsymbol{a},\boldsymbol{f})]\cdot e^{-r\cdot t}dt$$

$$s.t.\ \ \dot{\boldsymbol{x}} = \boldsymbol{G}(\boldsymbol{x},\boldsymbol{z},\boldsymbol{Y}(\boldsymbol{x},\boldsymbol{z},\Omega,\boldsymbol{a},\boldsymbol{f}))$$

So, the management problem is to select the “best” (i) fisheries management system, (ii) enforcement activities and (iii) penalty structure

- Very little research ... so far

Comprehensive Marine Use Fisheries Modelling

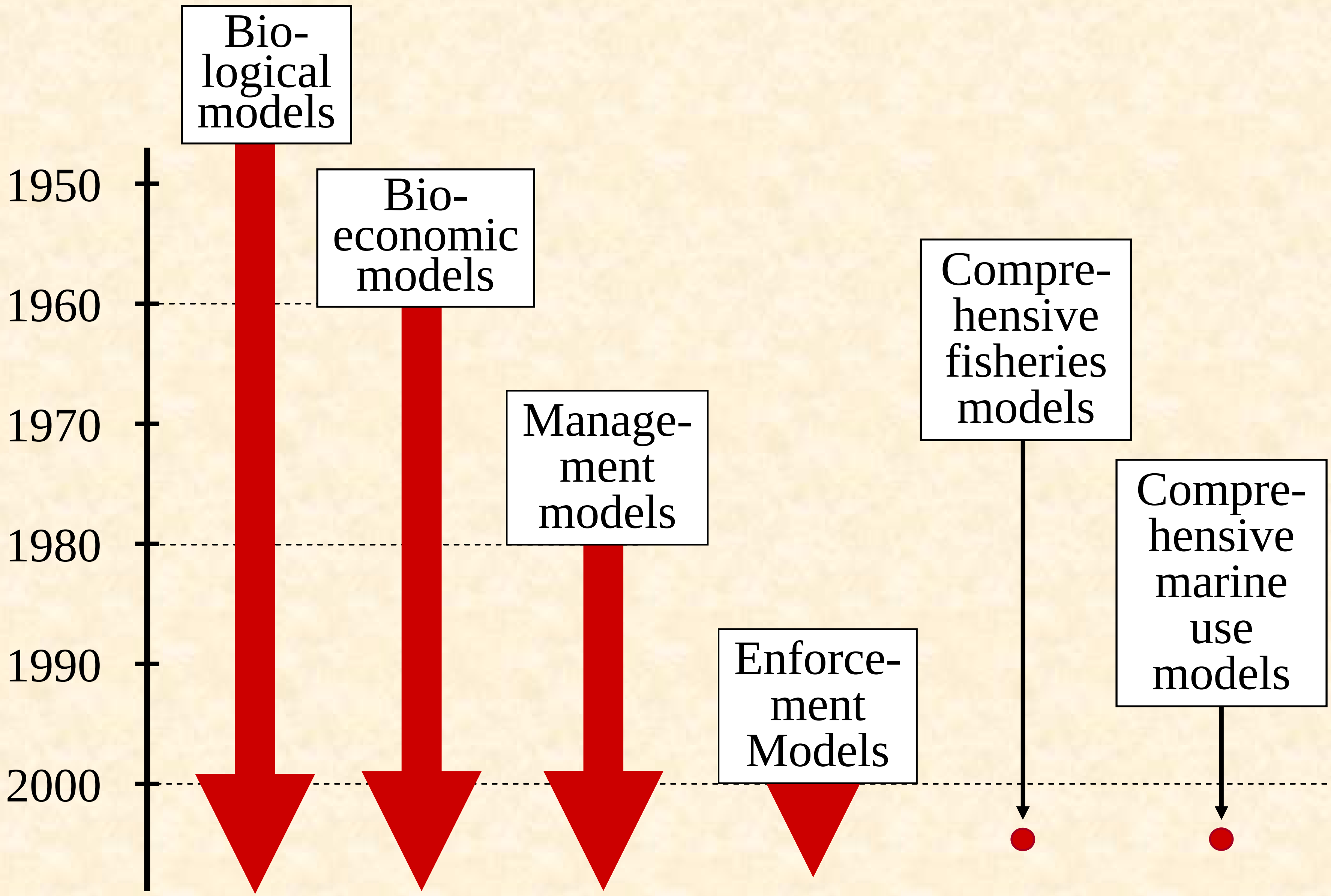
How should we arrange fisheries so as to maximize the different uses of marine resources?

$$\underset{\{\boldsymbol{a}, \boldsymbol{f}, \Omega\}}{Max} \int_0^\infty W(\boldsymbol{Y}(\boldsymbol{x}, \boldsymbol{z}, \Omega, \boldsymbol{a}, \boldsymbol{f}) - C(\boldsymbol{a}, \boldsymbol{f}); \boldsymbol{x}, \boldsymbol{z}) \cdot e^{-r \cdot t} dt$$

$$\text{s.t.} \quad \dot{\boldsymbol{x}} = \boldsymbol{G}(\boldsymbol{x}, \boldsymbol{z}, \boldsymbol{y})$$

Very little research on this

Approximate Time Line



Urgent Modelling Tasks

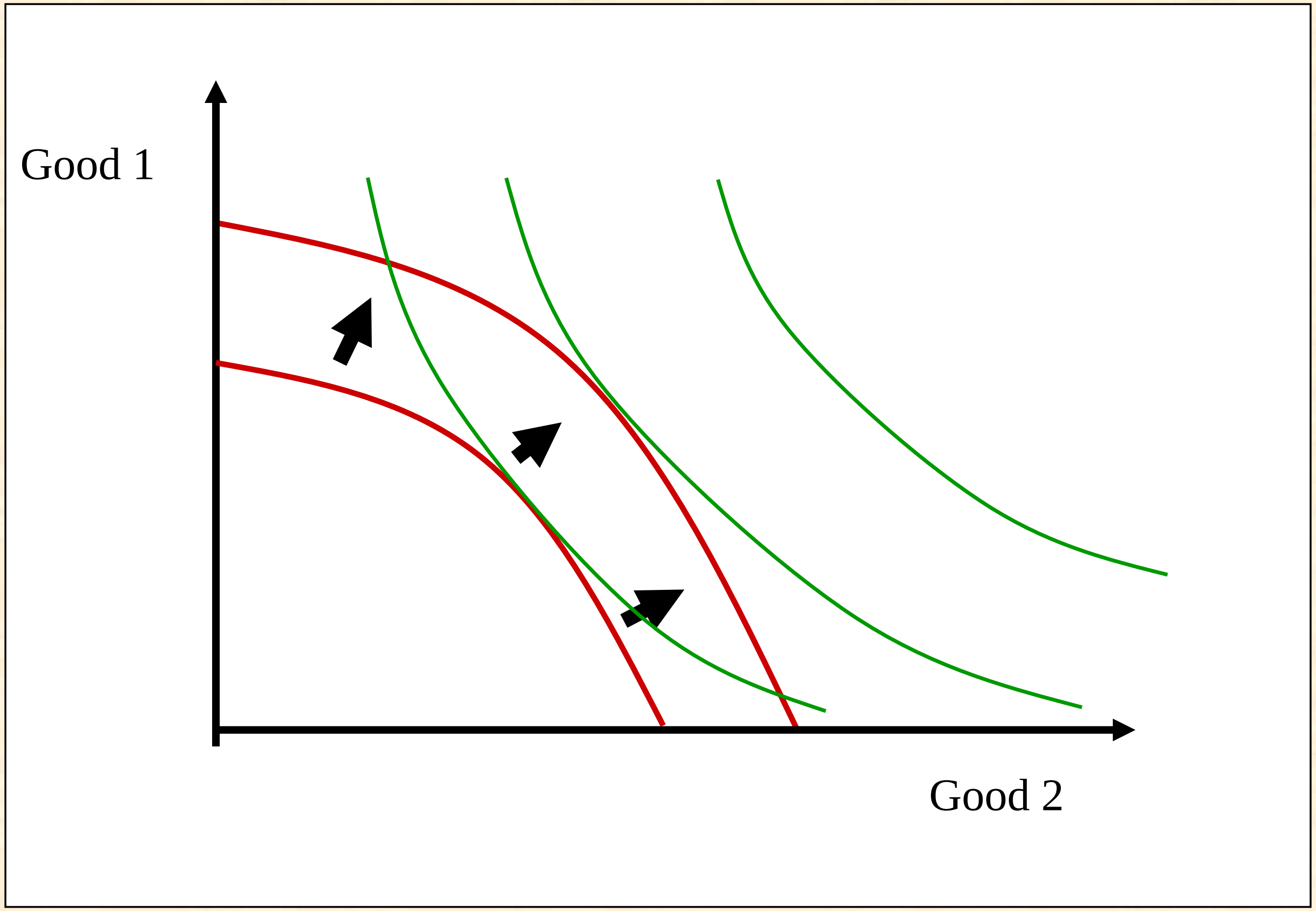
1. Enforcement modelling
2. Comprehensive fisheries modelling
3. Comprehensive marine use modelling

Plenty of work for the next 30 years!

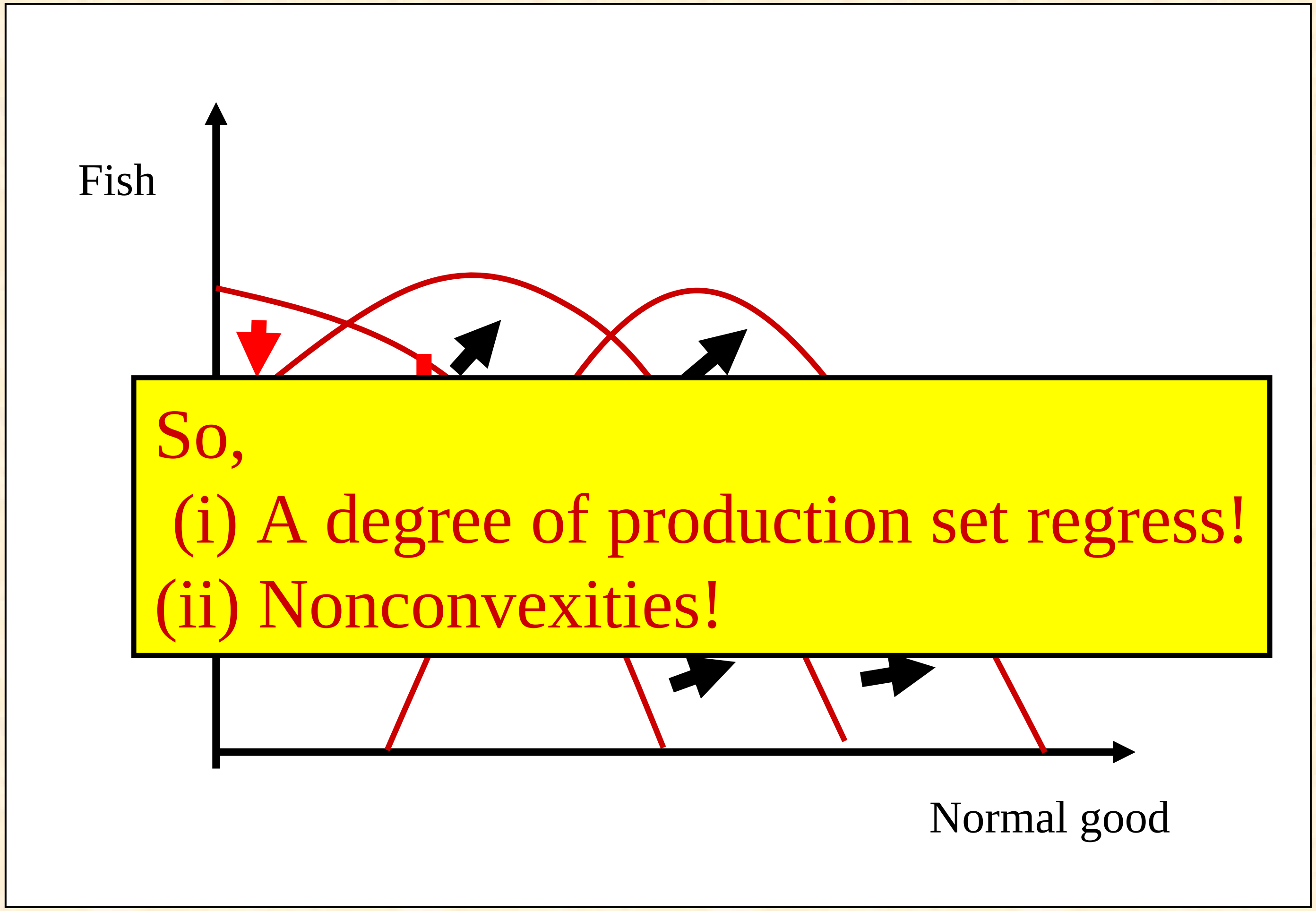
General equilibrium modelling

- The fishery in a economy wide context
- Research almost non-existent
- Pity, because the existence of a fishery (a renewable resource) can lead to “strange” results

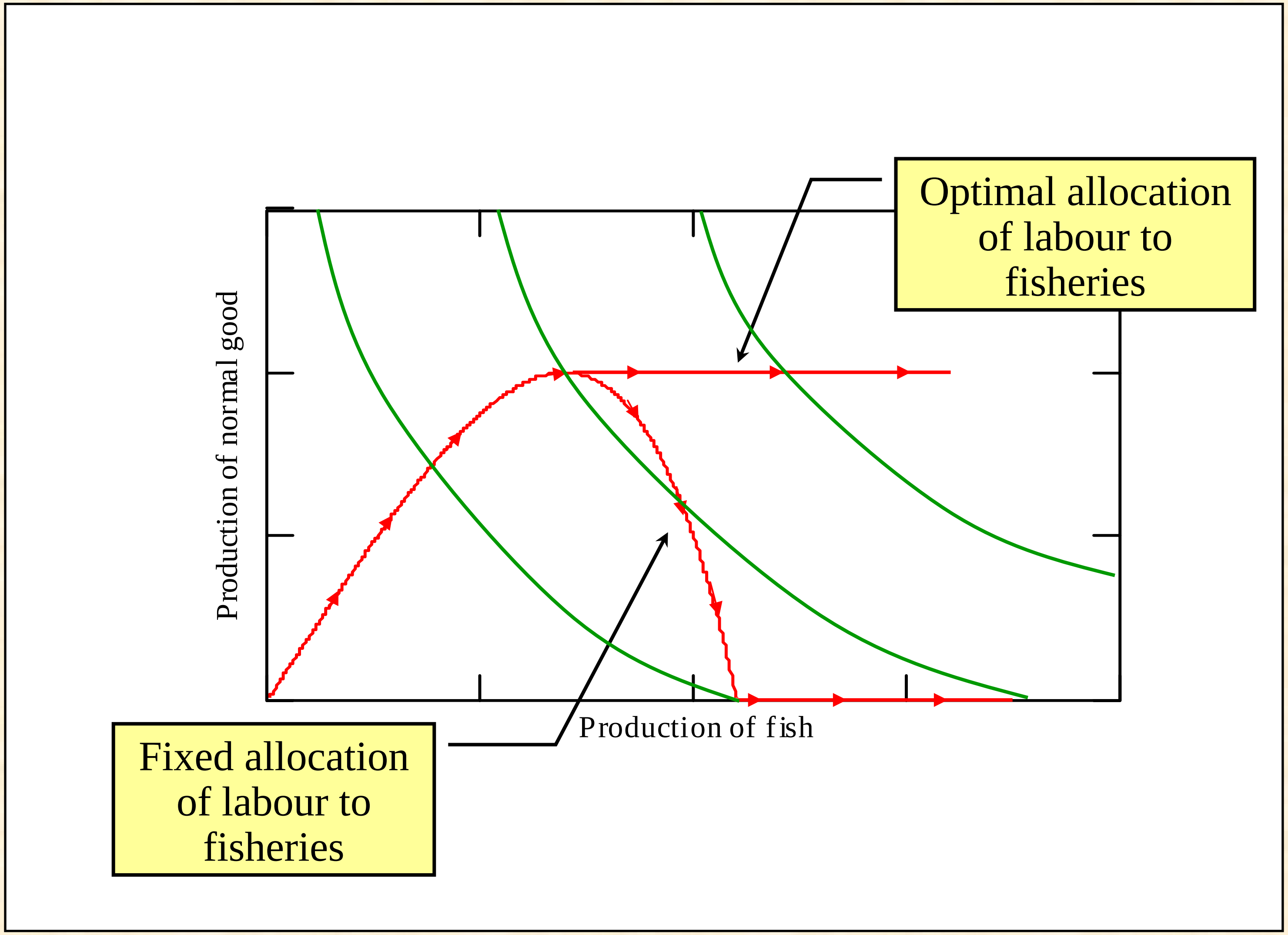
Usual economy-wide production set & technological progress



Fisheries-based production set & technological progress



Fisheries based production set: Possible expansion paths



Optimal feed-back paths

- A solution to the dynamic optimization problem
- A rule that relates stocks (biomass) to actions (harvests)
- Often referred to as a “catch rule”

$$q(t)=F(x(t))$$

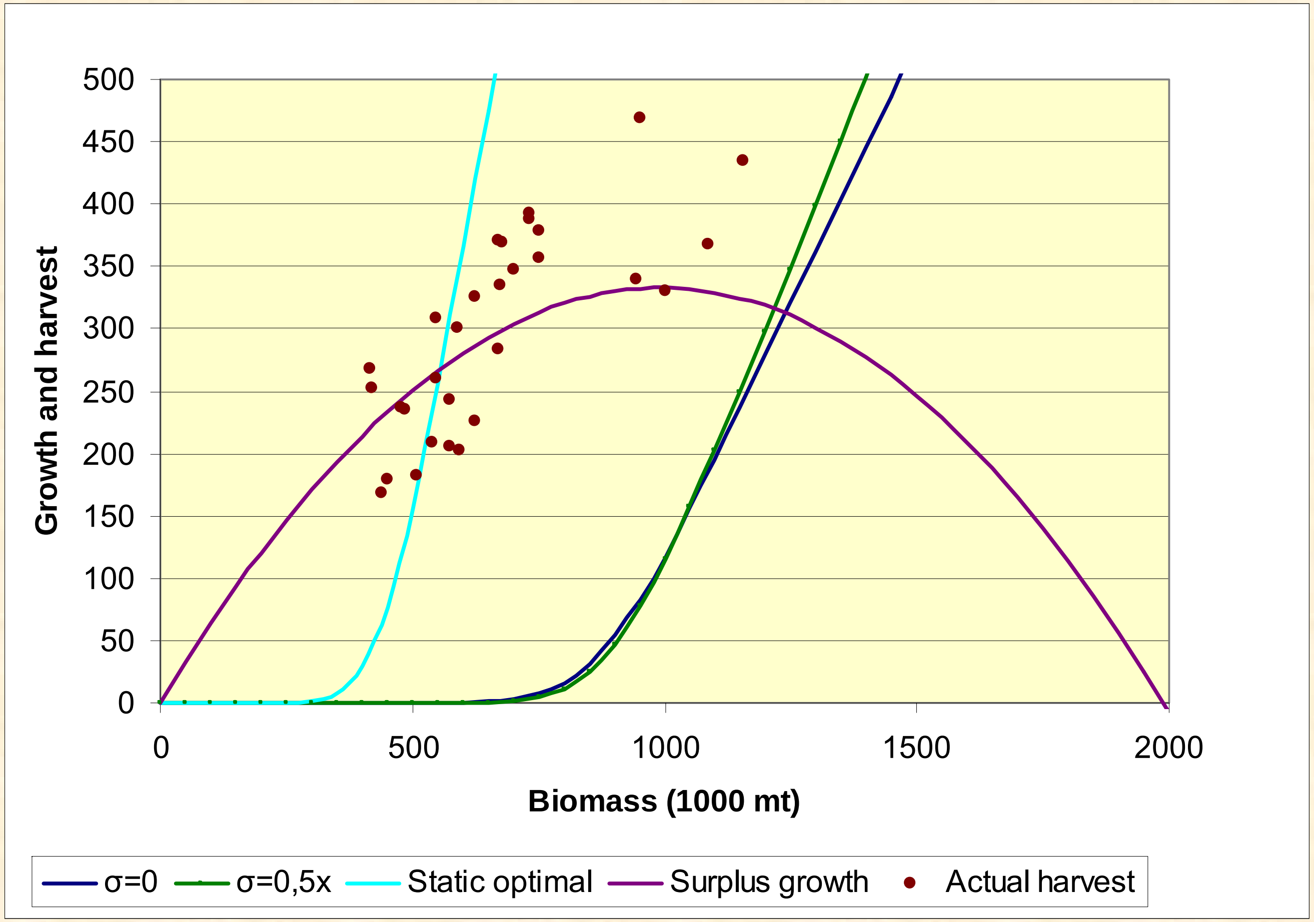
Extremely practical

- Only need to solve the dynamic maximization problem once
- Only need to observe the current state, the optimal action follows
- Particularly useful for TAC-based regimes
- Helpful to businesses (no political horse-trading, prediction is easier)

Calculation of optimal feed-back paths

- It is now perfectly feasible to locate optimal feed-back paths numerically (Research group: Sandal, Steinshamn, Arnason, Vestergaard, Agnarsson and others)
  - Desk/lap-top computers, widely available software (Mathlab, Mathematica etc)
  - Non-stochastic, single species, aggregative models (a couple of minutes)
  - Stochastic aggregative models (5-10 minutes)
  - Multi-species aggregative models (5-10 minutes)
  - Large scale models (probably feasible, a few hours maybe)

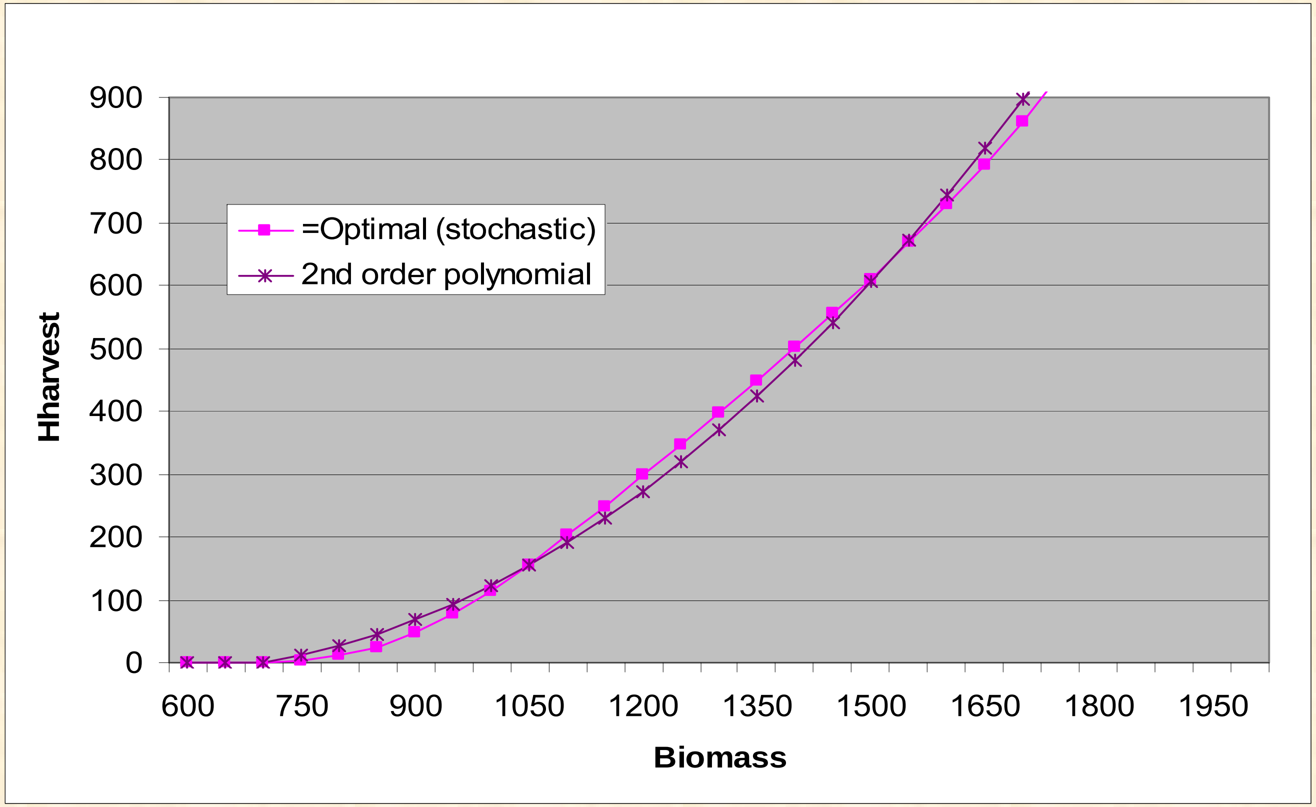
An example: Icelandic cod optimal feed-back paths



Approximate optimal feed-back paths

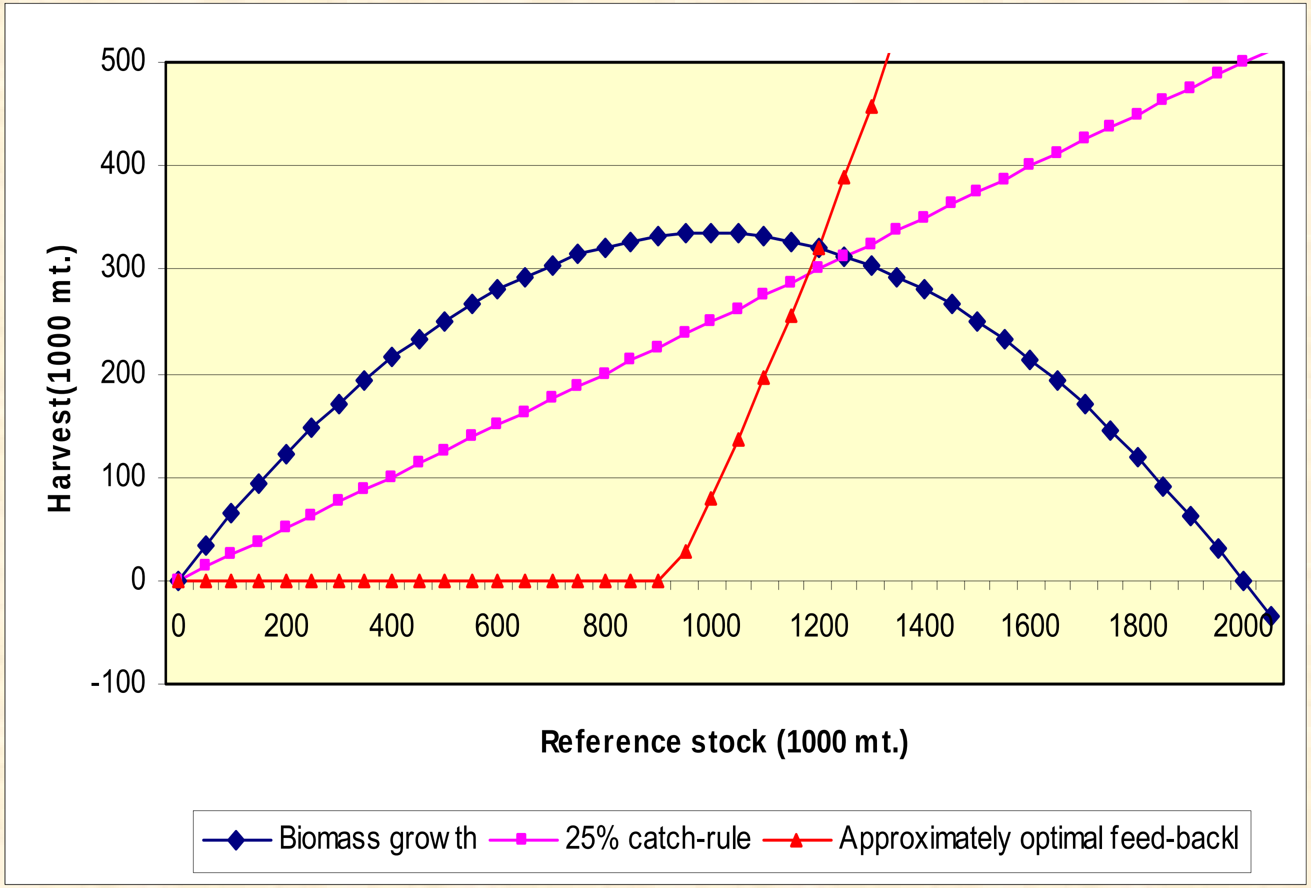
- It turns out that for many fisheries (probably most) optimal path surfaces are fairly flat!!
  - ⇒It doesn´t matter much to be <u>slightly</u> off the optimal path (provided the optimal equilibrium is approximately correct)
  - ⇒We can approximate optimal feed-back paths with low level polynomials or a set of linear splines
  - ⇒We can locate approximate optimal feed back paths with simple inexpensive programs (such as Mathcad) in seconds

Icelandic cod: 2nd order polynomial approximation to the optimal feed-back path



R^2=0.995. Loss in terms of present value <1%

Icelandic cod:
Approximately optimal vs. current policy



Two species optimal feed-back paths

- This is a feed-back rule which looks like

$$q_1(t)=F(x_1(t),\, x_2(t))$$
$$q_2(t)=F(x_1(t),\, x_2(t))$$

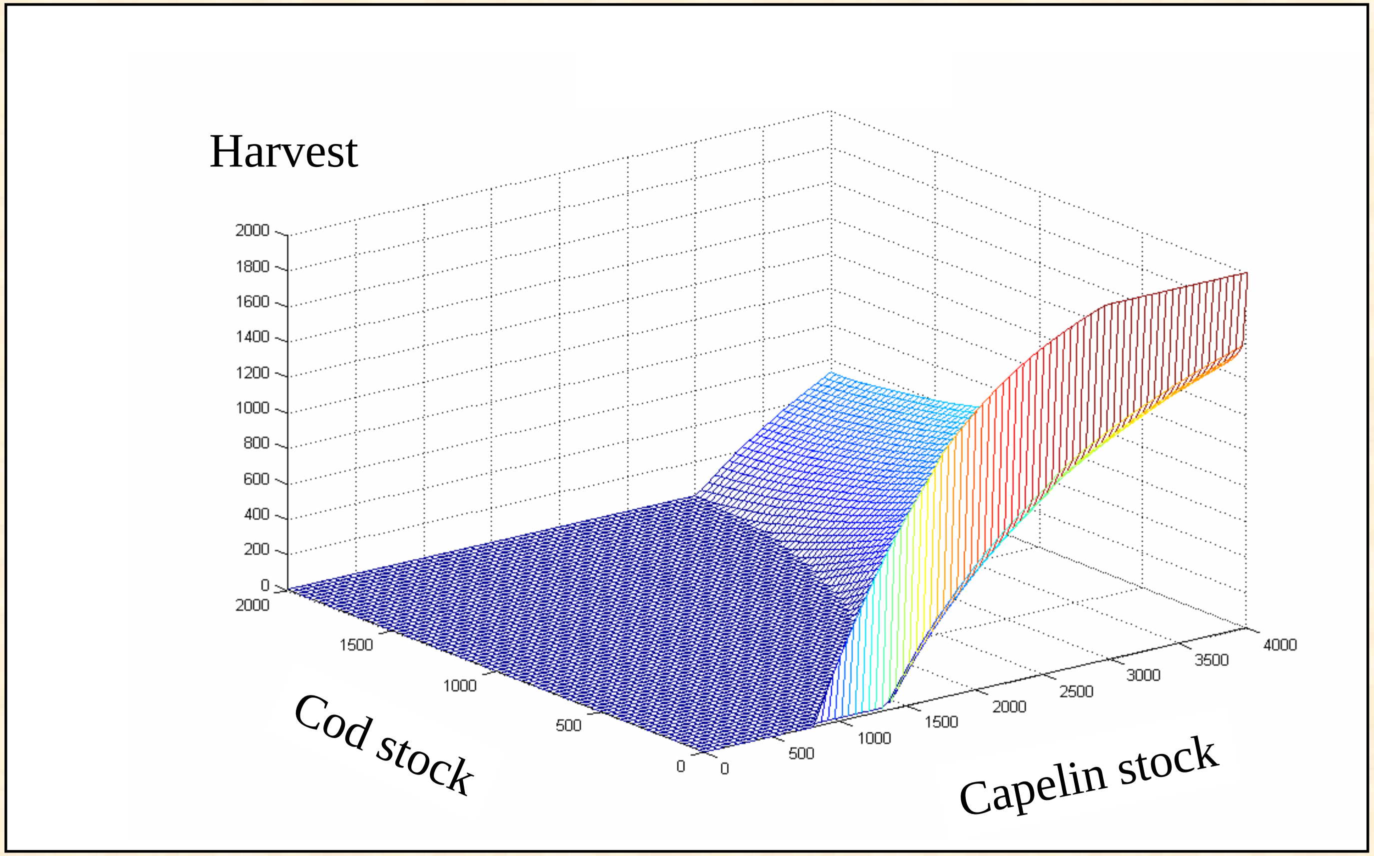
- Much more complicated and computationally demanding

An Example:
Icelandic cod & capelin

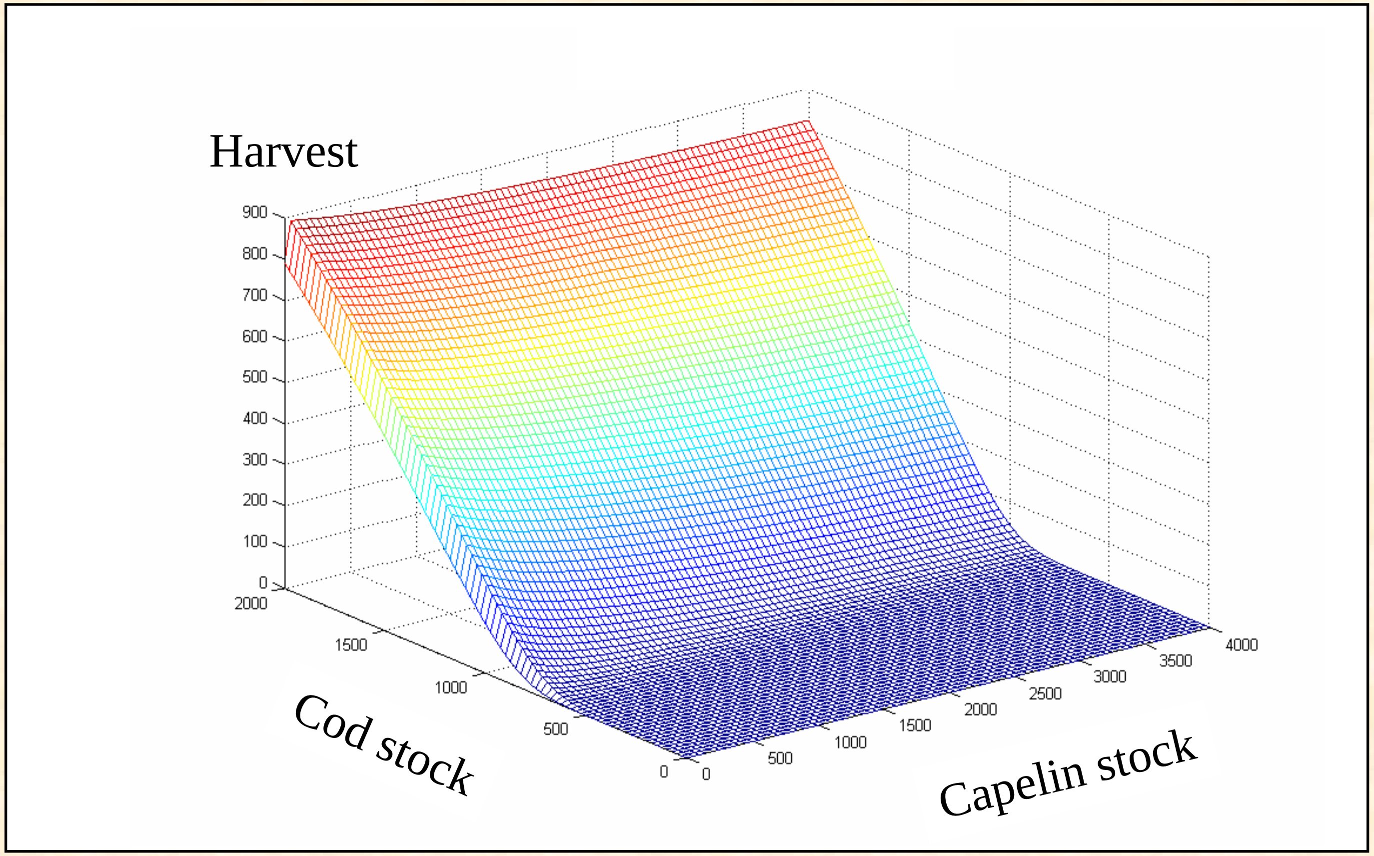
Basic Facts

- Cod MSY ≈ 320.000 mt.
- Capelin MSY ≈ 800.000 mt.
- Cod prays on capelin
- Cod is much more valuable

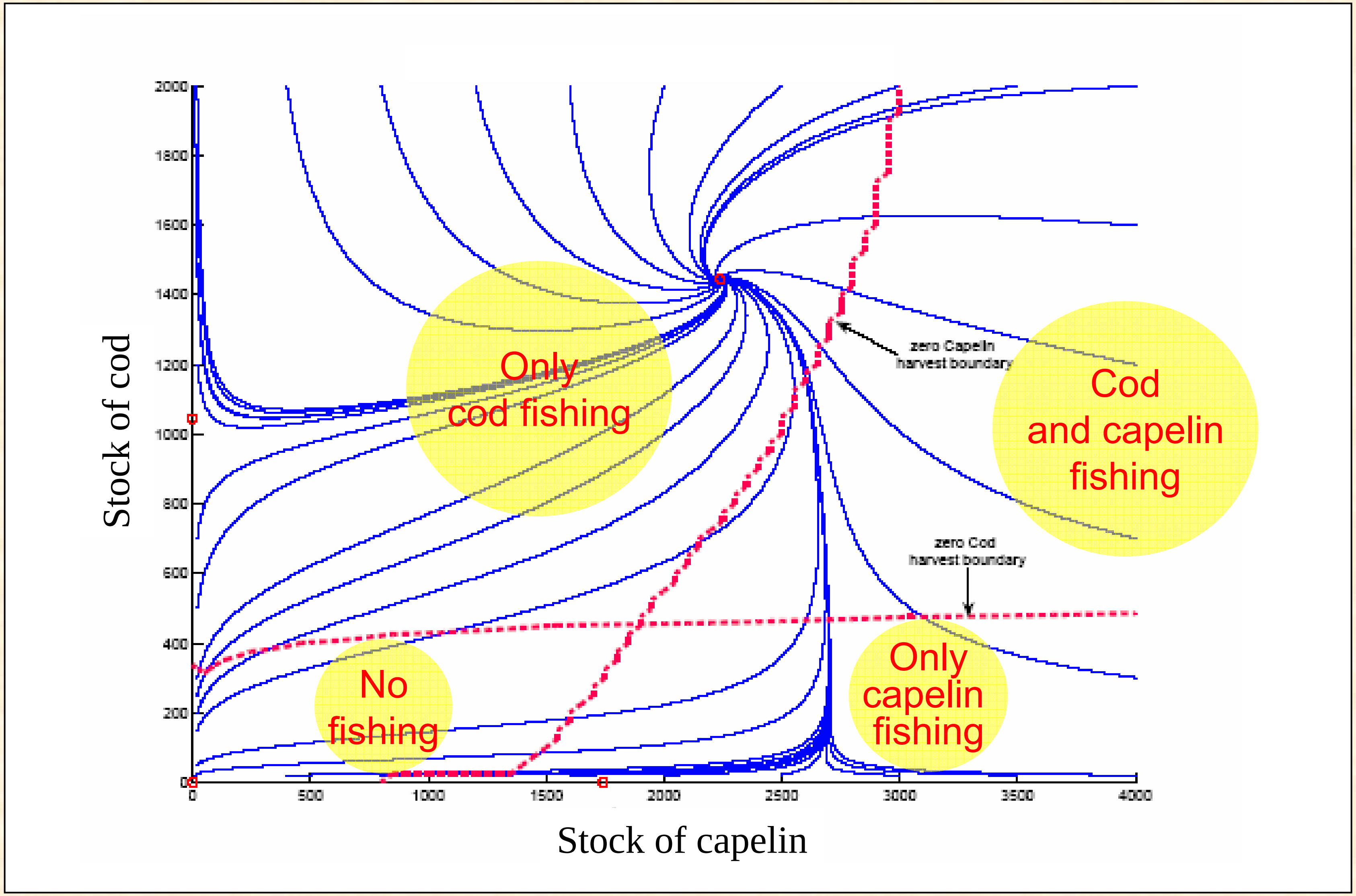
Feed-back harvest for capelin



Feed-back harvest for cod



Two species optimal feed-back paths: Icelandic cod and capelin

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