Organization

- 1. Objectives
- 2. Basic Points and Background
- 3. Traditional Bioeconomic Model
- 4. Bioeconomics with Technical Change
- 5. Empirical Application: Albacore Trolling
- 6. Empirical Results
- 7. Conclusions



1. Objectives

Objectives 1: Technical Change

- Introduce changes in technology and technical inefficiency into normative renewable resource management.
- Currently, only static technology & full technical efficiency.
- Disembodied w/out investment
- Embodied explicitly with investment
- Could easily introduce productivity indices.

Objectives 2: Economic Efficiency

- Traditional bioeconomic optimum is only scale efficiency.
  - Optimum scale of composite input, fishing effort, and composite output
- Overlooks broader Debreu-Farrell concept of economic efficiency.
  - Technical, allocative, & scale efficiency.
- Introduce technical & allocative inefficiency.

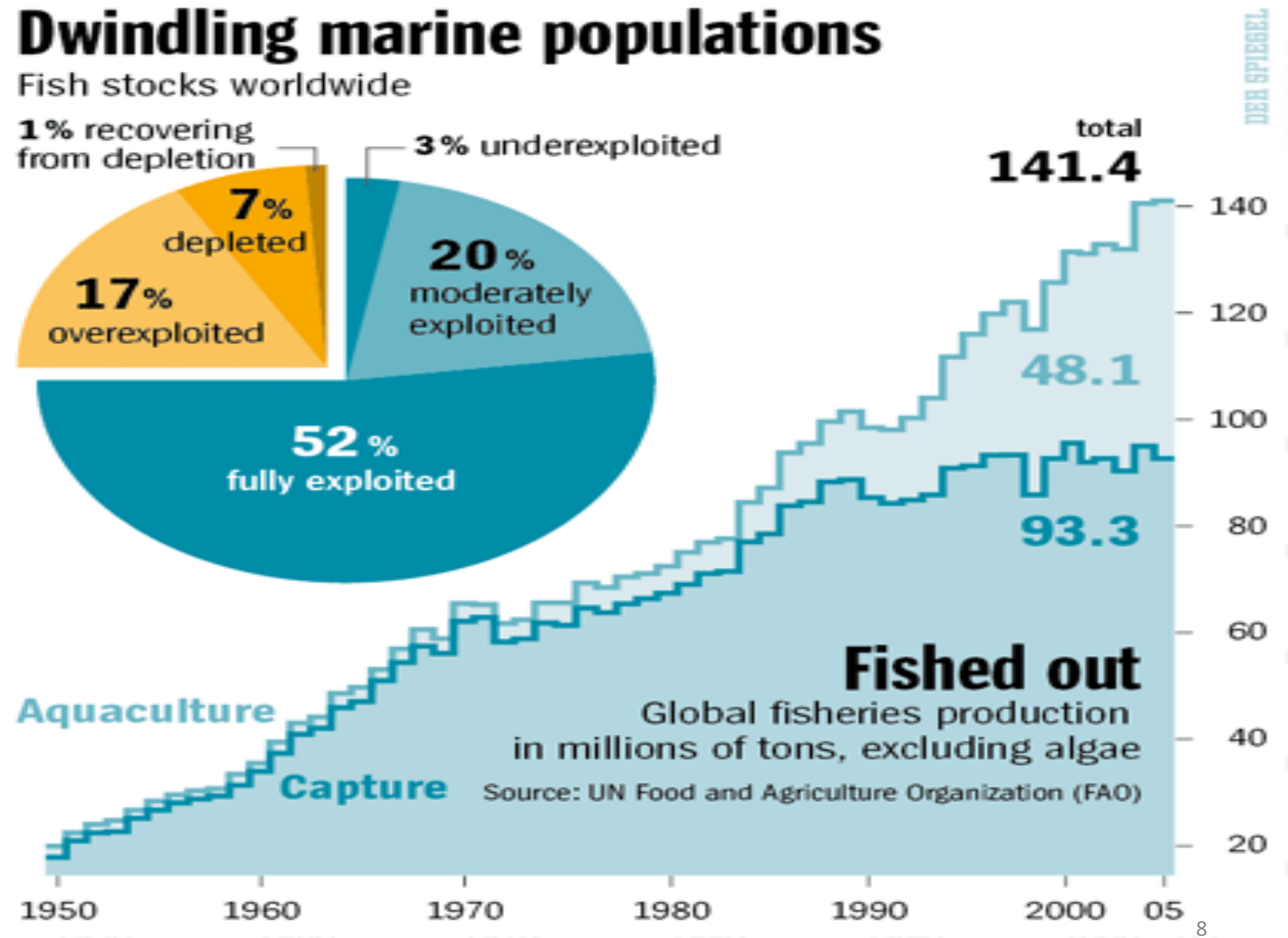
2. Basic Points & Background

Basic Points…(1)

- Overfished resource stocks (stock sizes less than MSY) can be explained as an economic optimum when accounting for technical change and private benefits and costs.
- Further, the optimal configuration of the fishing fleet (inputs) may differ as well.
- Don't necessary have to appeal to poorly structured property rights to explain overfished stocks.

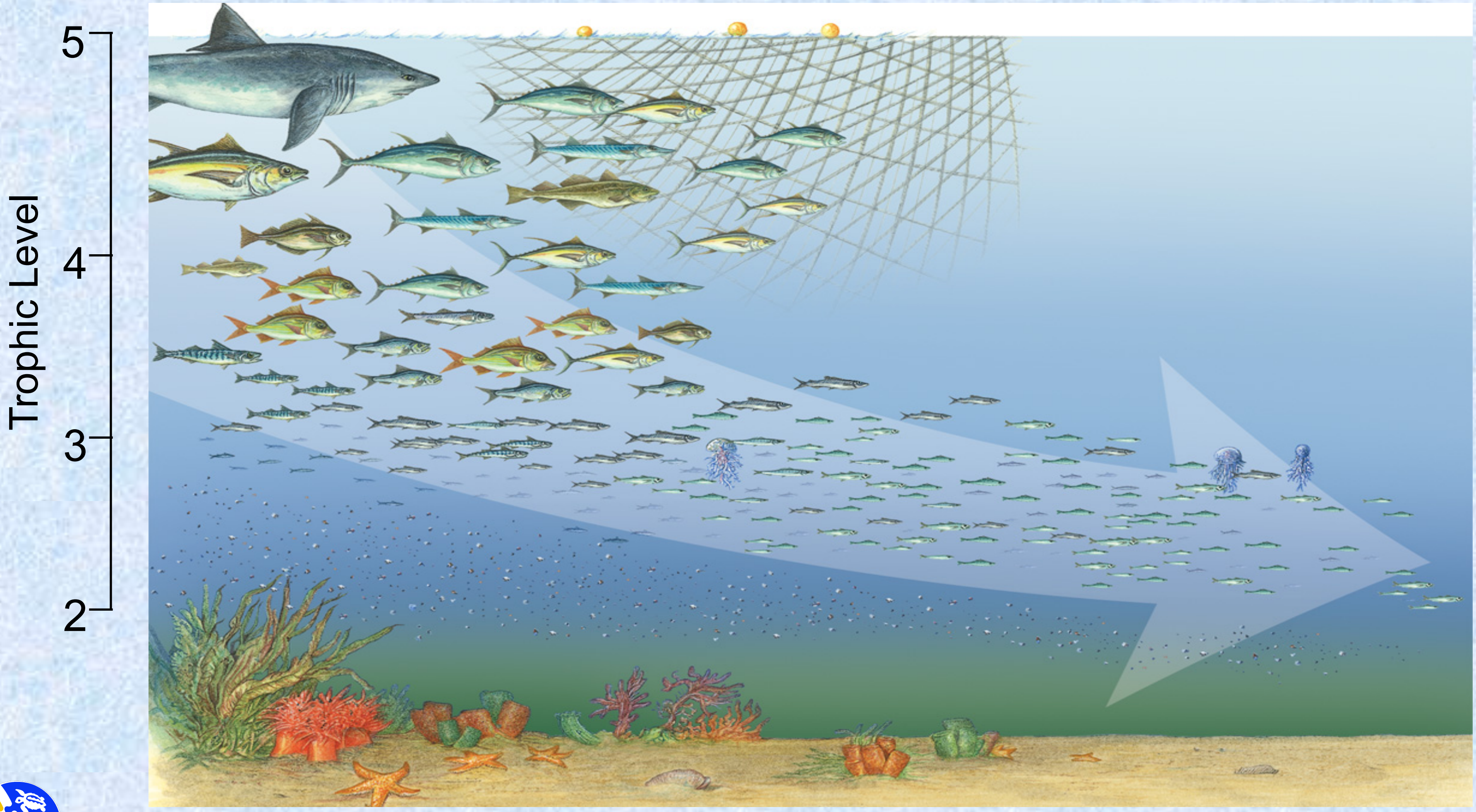
Basic Points…(2)

- Standard bioeconomic model concluded leave fish in water to lower harvest costs.
- Technical change takes care of problem of lowering cost
- So don't need to leave fish in the water over long run to lower costs.



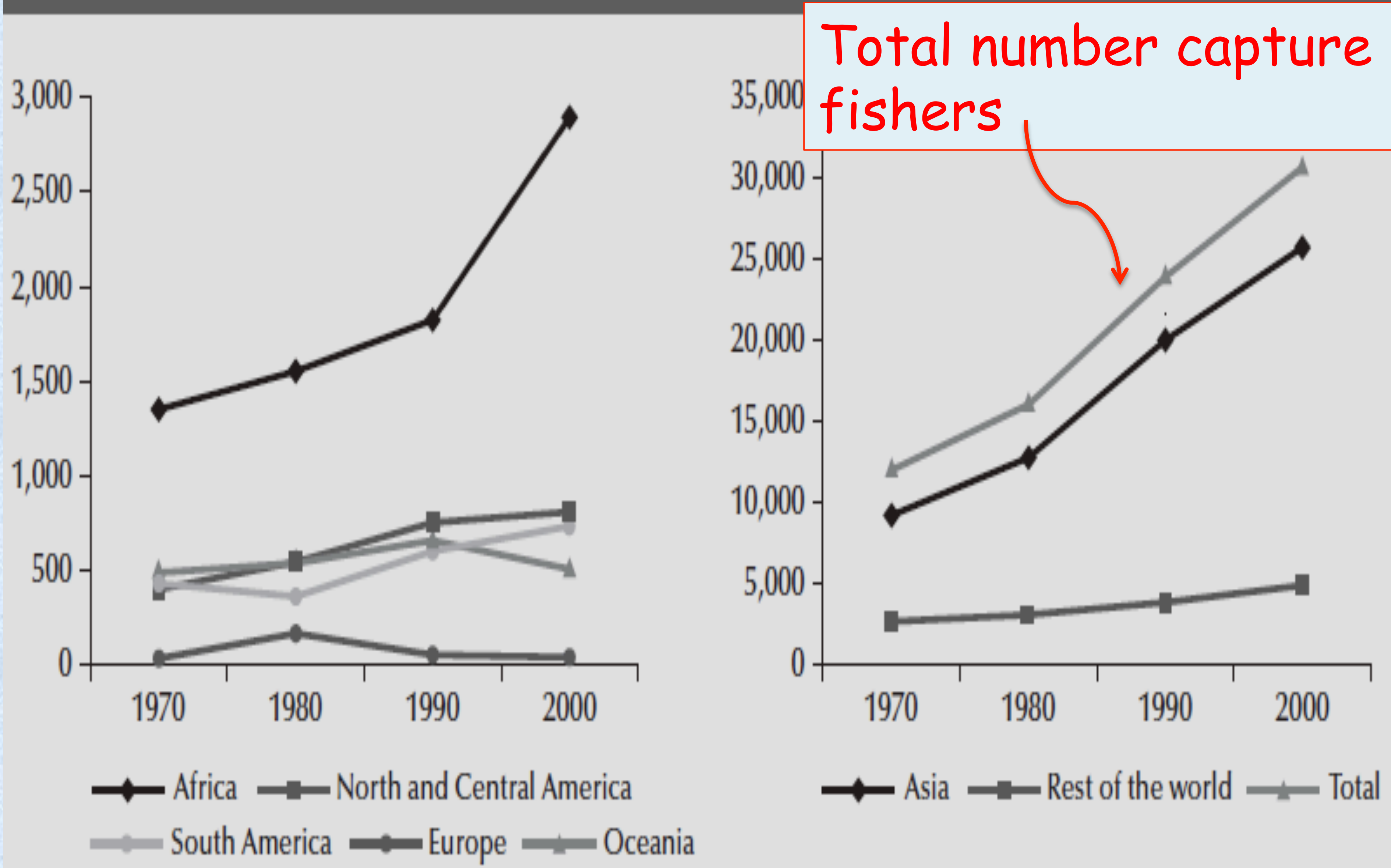
Dwindling marine populations
Fish stocks worldwide
1% recovering from depletion
3% underexploited
7% depleted
17% overexploited
20% moderately exploited
52% fully exploited
DER SPIEGEL
total
141.4
48.1
93.3
140
120
100
80
60
40
20
Aquaculture
Capture
Fished out
Global fisheries production in millions of tons, excluding algae
Source: UN Food and Agriculture Organization (FAO)
1950
1960
1970
1980
1990
2000
05

Not only do the biomasses decline, but their composition change…



Watson and Pauly In: Atlas of the Ocean

Figure 13 Total Number of Capture Fishers by Region (thousands 1,000)



Source: FAO Fisheries Circular No 929 (1970; 1990 data), SOFIA 2006 (1990, 2000, 2004 data)

3. Traditional Bioeconomic Model

Standard Bioeconomic Specification

- Fish are reduced by capture to private good from renewable common resource stock.
- Provide private direct use values in form of economic rent and consumer surplus (CV).
- Here, we'll assume price is constant and consider only economic rent.
- Standard economic formulation has assumed a static technology and full technical efficiency.

Classics of Normative Renewable Resource Economics

Clark, Colin W. *Mathematical Bioeconomics: The Optimal Management of Renewable Resources*, third edition. (New York: John Wiley and Sons, 2010.)

Clark, Colin W. and Gordon Munro. "The Economics of Fishing and Modern Capital Theory: A Simplified Approach," *Journal of Environmental Economics and Management* 2:2 (1975), 92-106.

Clark, Colin W., Frank Clarke, and Gordon Munro. "The Optimal Exploitation of Renewable Resource Stocks: Problems of Irreversible Investment," *Econometrica* 47:1 (1979), 25-47.

Golden Rule without Technical Change & Marginal Stock Effect

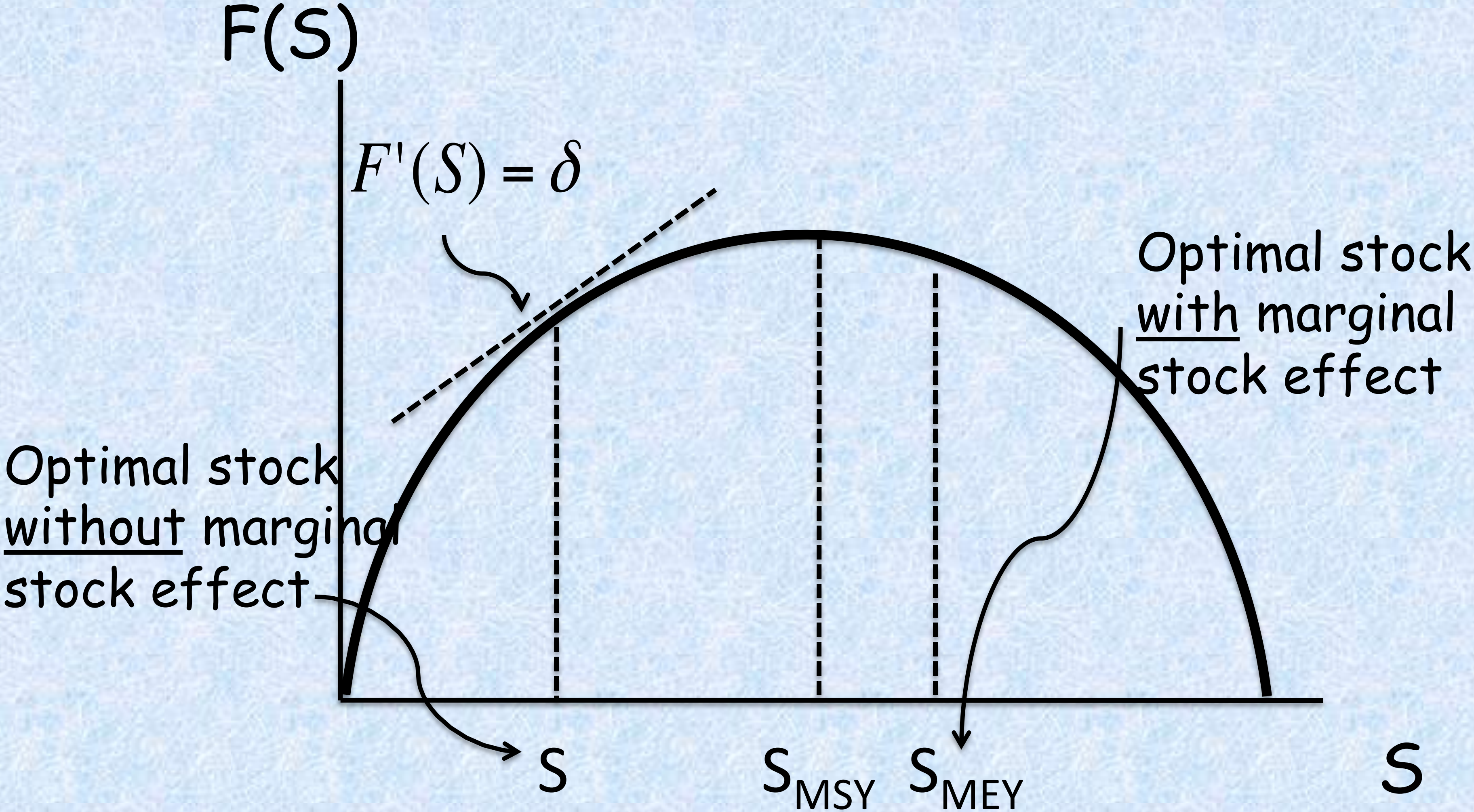
$$\frac{\partial F}{\partial S_t} + \frac{c\,F(S)}{S(PqS - c)} = \delta$$

Marginal productivity of resource stock

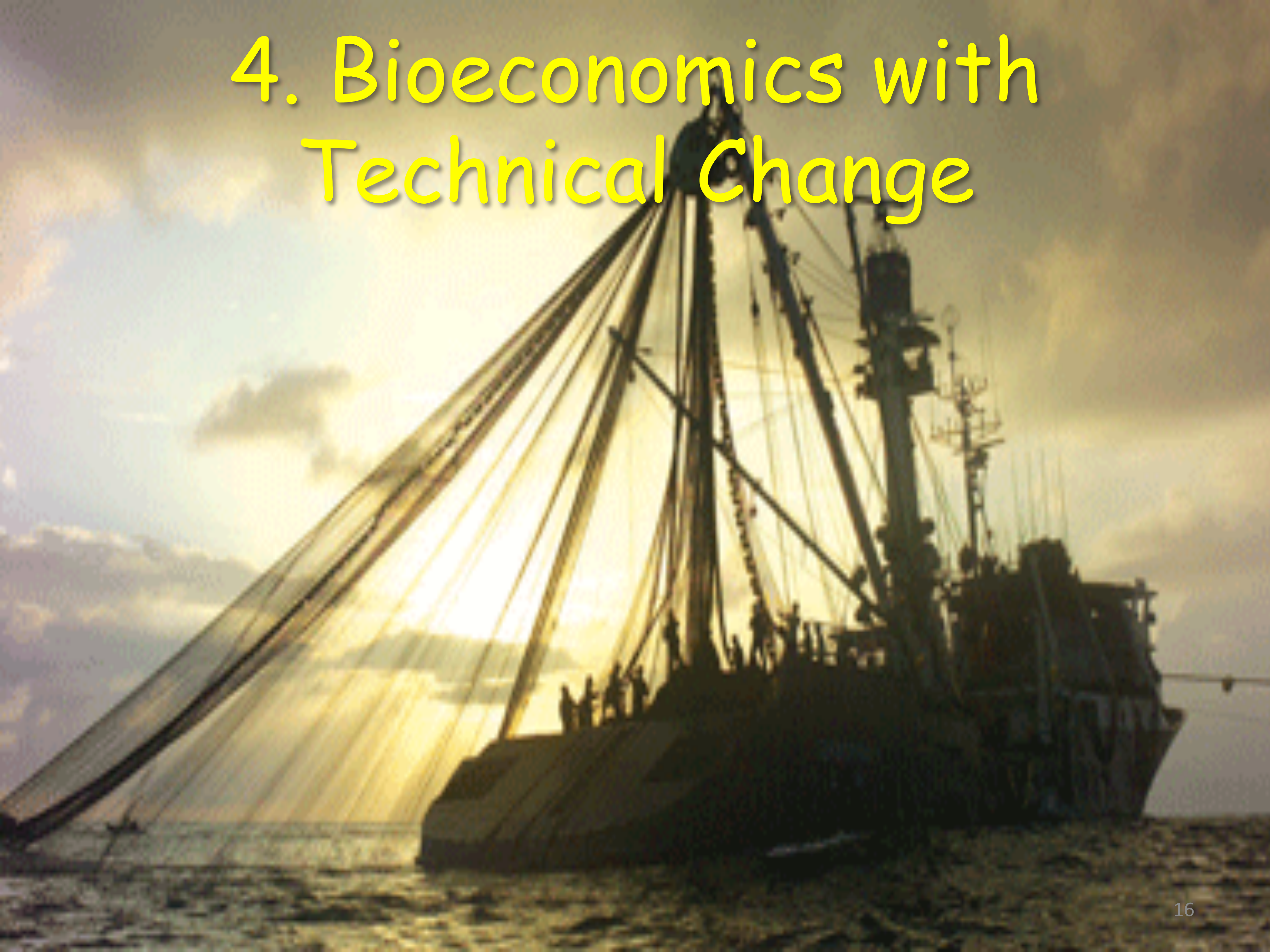
Social discount rate

Marginal stock effect
(cost savings from fish in water)

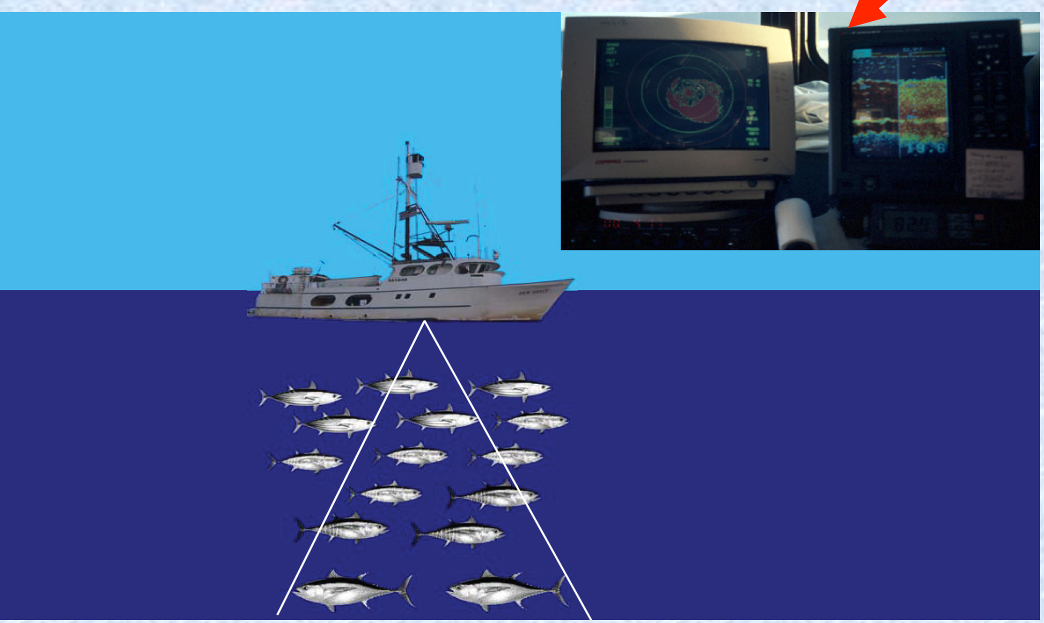
Optimum Stock w/out Technical Change & w. and w/out Marginal Stock Effect



4. Bioeconomics with Technical Change



Now Add In Technical Change



Two Basic Cases

- Case 1: Disembodied technical change
- Case 2:
  - Disembodied & embodied technical change,
  - imperfectly malleable capital,
  - investment.

- We are looking at "balanced growth path" of stock, catch and effort.

Graham-Schaefer Production Frontier with Disembodied Technical Change

$$Y_t = qS_tE_te^{\lambda t - \mu(t,Z)}$$

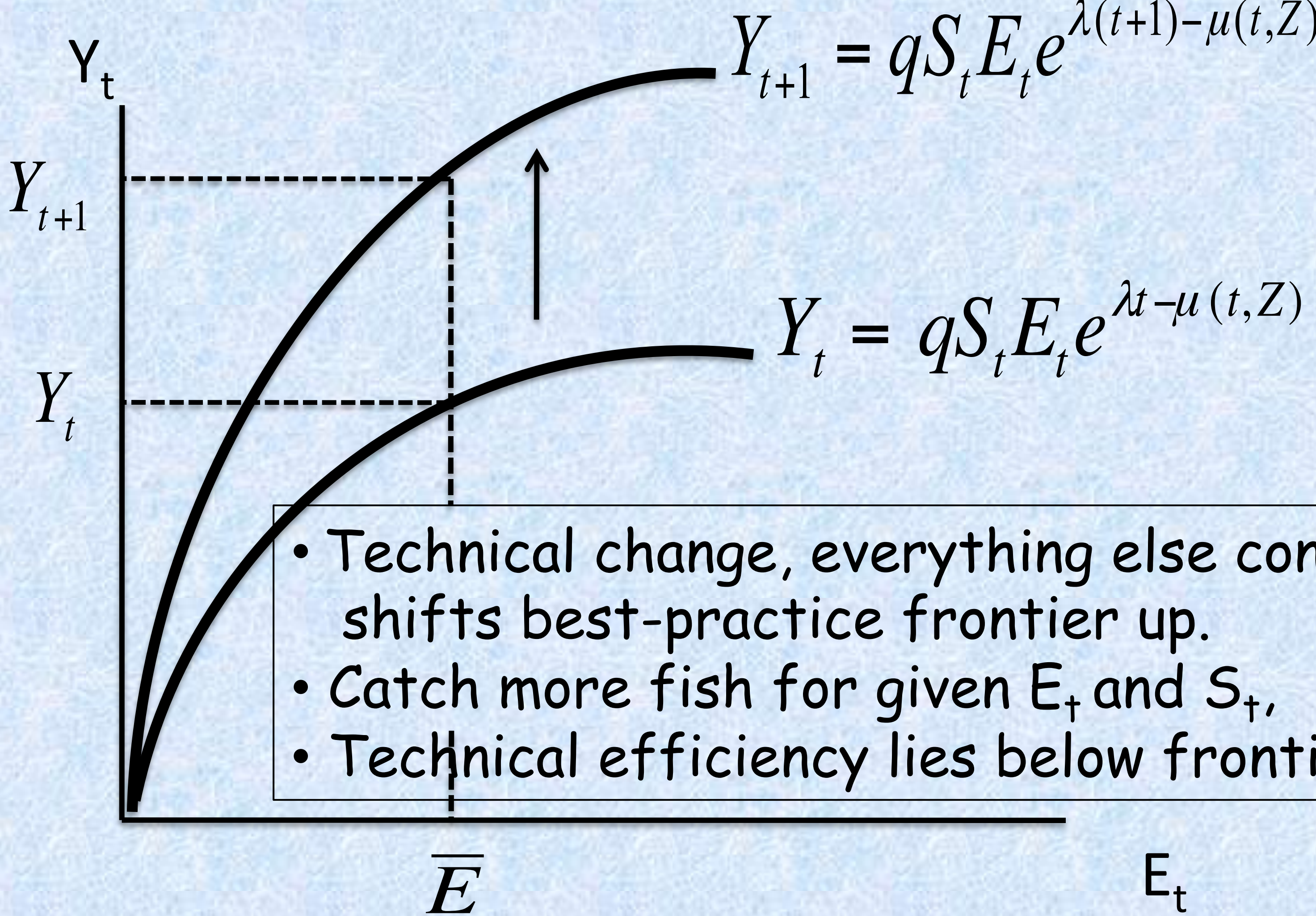
What's new:

Y_t = catch
q = catchability coefficient
E_t = effort

Effort aggregator function under Leontief-Sono separability & allocative Efficiency. Linear homogeneous.

λ = rate of technical change (constant, Hick's neutral)
- μ(t,Z) = time-varying technical efficiency

Disembodied and exogenous technical Change



- Technical change, everything else constant, shifts best-practice frontier up.
- Catch more fish for given E_t and S_t,
- Technical efficiency lies below frontier.

Embodied technical Change

$$Y_t = qS_t\hat{E}_t e^{\lambda t - \mu(t,Z)}$$

Technical inefficiency

Disembodied

Embodied

Where

$$\hat{E}_t = f(X_{1t}, \Psi_t X_{2t}) = f(X_{1t}, J_t)$$

Effort aggregator function
Leontief separability
Allocative efficiency

X_{1t} = variable inputs
X_{2t} = capital inputs (CCM implicitly assumes limiting factor & Leontief separability)
J_t = capital inputs measured in efficiency units
Ψ_t = rate of embodied (investment-specific) technical change

Disembodied & Embodied Technical Change Harvest Function

Leontief aggregation of effort, capital limiting factor

$$Y_t = q\tilde{\bar{E}}_t S_t e^{\lambda t - \mu(t,Z)} = qAJ_t S_t e^{\lambda t - \mu(t,Z)}$$

$$= qAX_{2t} S_t e^{(\lambda + M_2\psi)t - \mu(t,Z)}$$

Technical Inefficiency

Embodied

Capital limiting factor

Disembodied

Objective Function with Disembodied Technical Change & Technical Efficiency

If $\delta > 0$ is a constant denoting the continuous social rate of discount, the objective is:

$$PV(\pi) = \int_0^\infty \pi\left[Y_t, S_t\right] e^{-\delta t} dt \text{ subject to } dS/dt = F(S_t) - Y_t \text{ and } S_0 = S(0), \text{ where}$$

$$\pi_t\left[P, c, q, S_t, Y_t, e^{\lambda t - \mu(t,Z)}\right] = PY_t - c\frac{Y_t}{qS_t e^{\lambda t - \mu(t,Z)}} = \left[P - \frac{c}{qS_t e^{(\lambda t - \mu(t,Z))}}\right] Y_t$$

Hamiltonian with Exogenous Disembodied Technical Change & Technical Efficiency

The present value Hamiltonian with technical efficiency and technical change is:

$$H = e^{-\delta t}\pi\left[Y_t, S_t\right] + \alpha(t)(F(S_t) - Y_t) = e^{-\delta t}(P - \frac{c}{qSe^{(\lambda t - \mu(t,z))}})Y_t + \alpha(t)(F(S_t) - Y_t), \qquad (3)$$

where α(t) is the present value multiplier. The first-order conditions for a maximum are:

$$\frac{\partial H}{\partial Y_t} = e^{-\partial t}\frac{\partial \pi}{\partial Y_t} - \alpha(t) = e^{-\partial t}(P - \frac{c}{qS_t e^{\lambda t - \mu(t,z)}}) - \alpha(t) = 0 \qquad (4)$$

$$\frac{\partial H}{\partial S_t} = e^{-\partial t}\frac{\partial \pi}{\partial S_t} + \alpha(t)\frac{\partial F}{\partial S_t} = e^{-\partial t}\frac{c}{qS_t{}^2 e^{\lambda t - \mu(t,z)}}Y + \alpha(t)\frac{\partial F}{\partial S_t} = -\dot{\alpha}(t)\ . \qquad (5)$$

Objective Function with Disembodied & Embodied Technical Change & Technical Efficiency

$$PV(\pi) = \int_0^\infty \{\pi\,[\tilde{E}_t, S_t] - c_f I_t\} e^{-\delta t} dt$$

$$= \int_0^\infty \{pq\phi_t A X_{2t} S_t e^{(\lambda + M_2\psi)t - \mu(t,Z)} - c_v \phi_t A X_{2t} - c_f I_t\} e^{-\delta t} dt$$

subject to

$$dS_t/_{dt} = F(S_t) - Y_t = F(S_t) - \; q\phi_t A X_{2t} S_t e^{(\lambda + M_2\psi)t - \mu(t,Z)}$$

$$dX_{2t}/_{dt} = I_t - \gamma X_{2t}$$

$0 \le \phi_t \le 1$,

where c_v denotes costs for variable inputs and let unit investment cost be c_f. We follow

Hamiltonian

$$H(\phi_t, I_t, S_t, X_{2t}, \alpha(t), \beta(t)) = \{pq\phi_t A X_{2t} S_t e^{(\lambda + M_2\psi)t - \mu(t,Z)} - \; c_v \phi_t A X_{2t} - c_f I_t\} e^{-\delta t}$$
$$+ \alpha(t)\{F(S_t) - \; q\phi_t A X_{2t} S_t e^{(\lambda + M_2\psi)t - \mu(t,Z)}\} + \beta(t)\{I_t - \gamma X_{2t}\}$$
$$= \{e^{-\delta t}(pqAX_{2t} S_t e^{(\lambda + M_2\psi)t - \mu(t,Z)} - c_v A X_{2t}) - \alpha(t) q A X_{2t} S_t e^{(\lambda + M_2\psi)t - \mu(t,Z)}\}\phi_t +$$
$$\{\beta(t) - c_f e^{-\delta t}\} I_t + \; \alpha(t) F(S_t) - \beta(t)\gamma X_{2t},$$

where $\beta(t)$ is a present value multiplier The Hamiltonian is linear in ϕ_t and I_t, and hence

Solow Residual & Embodied Tech Change

Given full technical efficiency and full capacity utilization and linear homogeneity in effort (coef=1) (Hulten *AER* 1992, Squires *Rand J. Econ.* 1992):

$$\dot{Y}_t = \left(1 - M_{2t}\right)\dot{X}_{1t} + M_{2t}\dot{X}_{2t} + \dot{S}_t + M_{2t}\psi_t + \lambda$$

Capital cost share

Rearranging:

$$\dot{T} = \lambda + M_{2t}\psi_t$$

$$= \dot{Y}_t - \left(1 - M_{2t}\right)\dot{X}_{1t} - M_{2t}X_{2t} - \dot{S}_t$$

Embodied Technical Change:

$$\psi_t = \frac{\left[\dot{T} - \lambda\right]}{M_{2t}}$$





Golden Rule: Disembodied Technical Change, Leontief-Sono Separability, & Technical Efficiency

$$\frac{\partial F}{\partial S_t} + \frac{c\,F(S)}{S(PqSe^{\lambda t - \mu(t,z)} - c)} + \frac{c(\lambda - \partial \mu(t,z)/\partial t)}{(PqSe^{\lambda t - \mu(t,z)} - c)} = \delta$$

What's new

Marginal stock effect

Social discount rate

Marginal productivity of resource stock

Marginal technology effect

Singular solution for resource stock in time *t*:

$$S_t^* = \frac{K}{4}\left[\left[\frac{c}{PqKe^{\lambda t-\mu(t,Z)}}+1-\frac{\delta}{r}\right]+\sqrt{\left[\frac{c}{PqKe^{\lambda t-\mu(t,Z)}}+1-\frac{\delta}{r}\right]^2+\frac{8c(\delta+\lambda-\partial\mu\left(t,Z\right)/\partial t)}{PqKre^{\lambda t-\mu(t,Z)}}}\right]$$

- No steady-state solution.
- Optimal level of stock declines over time.
- Because profit increases with technical progress.

Golden Rule: Disembodied & Embodied Technical Change, Leontief Separability & Capital Limiting Factor, Explicit Investment

$$\frac{\partial F}{\partial S_t}+\frac{\left(c_vA+c_f(\gamma+\delta)\right)F(S_t)}{\left(PqAS_te^{(\lambda+M_2\psi)t-\mu(t,Z)}-\left(c_vA+c_f(\gamma+\delta)\right)\right)S_t}+\frac{\left(c_vA+c_f(\gamma+\delta)\right)\left(\lambda+M_2\psi-\partial\mu(t,Z)/\partial t\right)}{PqAS_te^{(\lambda+M_2\psi)t-\mu(t,Z)}-\left(c_vA+c_f(\gamma+\delta)\right)}=\delta$$

Embodied technical change

(Note addition of investment costs as capital services price)

$$S_t^{***}=\frac{K}{4}\left[\left[\frac{c_vA+c_f(\gamma+\delta)}{PqAKe^{(\lambda+M_2\psi)t-\mu(t,Z)}}+1-\frac{\delta}{r}\right]+\sqrt{\left[\frac{c_vA+c_f(\gamma+\delta)}{PqAKe^{(\lambda+M_2\psi)t-\mu(t,Z)}}+1-\frac{\delta}{r}\right]^2+\frac{8\left(c_vA+c_f(\gamma+\delta)\right)\left(\delta+\lambda+M_2\psi-\partial\mu(t,Z)/\partial t\right)}{PqAKe^{(\lambda+M_2\psi)t-\mu(t,Z)}}}\right]$$

Over time, the two terms with profit decline to approach 0, giving $F'(S) = \delta$

$$\frac{\partial F}{\partial S_t} + \frac{\left(c_v A + c_f\left(\gamma+\delta\right)\right)F(S)}{S(PqSe^{\left(\lambda+M_2\psi\right)t-\mu(t,z)} - \left(c_v A + c_f\left(\gamma+\delta\right)\right))} +$$

$$\frac{c(\lambda + M_2\psi - \partial\mu(t,z)/\partial t)}{(PqSe^{\left(\lambda+M_2\psi\right)t-\mu(t,z)} - \left(c_v A + c_f\left(\gamma+\delta\right)\right))} = \delta$$

Rises over time

- **Declines over time.**
- **As t → ∞, these two terms approach 0, assuming constant full technical efficiency.**

Declining Stock Levels Out

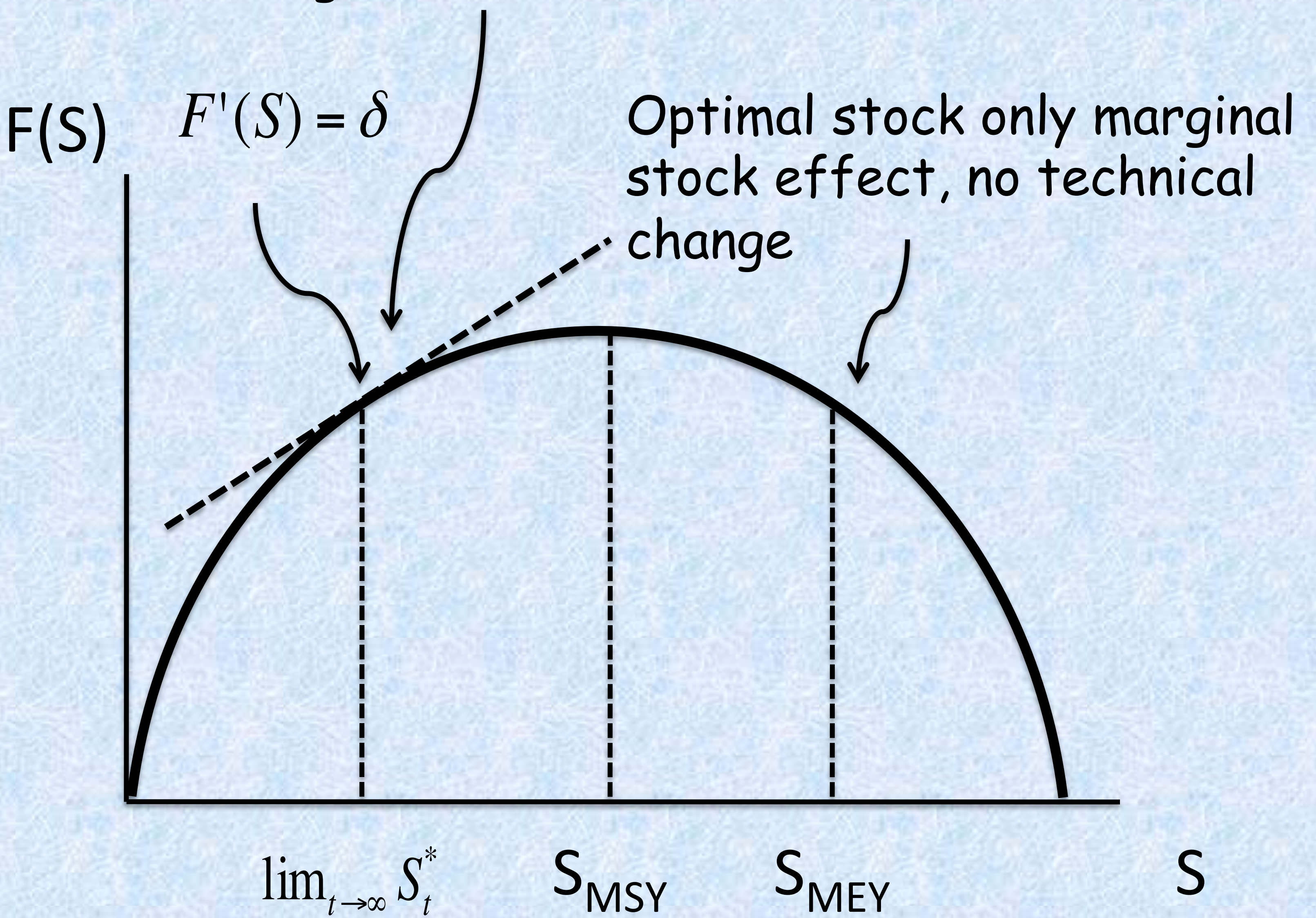
Intuitively, the terms involving $(\lambda + M_2\psi)t$ approach 0 in the limit as *t* approaches infinity with full technical efficiency, giving:

$$\lim_{t\to\infty} S_t^* = \frac{K}{4}\left[\left[1-\frac{\delta}{r}\right]+\sqrt{\left[1-\frac{\delta}{r}\right]^2}\right] \leq S_{MSY}$$

In static case where $\delta = 0$

$$\lim_{t\to\infty} S_t^* = \frac{K}{2} = S_{MSY}$$

Limit to optimal stock with both marginal stock effect and technical change over infinite time horizon



5. Empirical Application: Albacore Trolling

Empirical Application

- Simulation of U.S.-Canadian Pacific coast albacore troll fleet
- Data: 1981-2007 U.S. & 1991-2007 Canada.
- Fish in same waters under international treaty.
- Predominately electronic process innovations for communication, navigation, and fish-finding.

Graham-Schaefer Best-Practice Production Frontier:

$$\ln Y_{it} = \alpha + \beta_1 lnE_{it} + \beta_2 lnS_{it} + \lambda t + a_i + v_{it},$$

The translog effort aggregator function is:

$$\ln E_{it} = \alpha + \alpha_1 \ln X_{1it} + \alpha_2 \ln X_{2it} + \alpha_{12} \ln X_{1it} \ln X_{2it} + \alpha_{11} \ln X_{1it}^2 + \alpha_{22} \ln X_{2it}^2 ,$$
$$+ a_i + a_{i1} X_{1it} + a_{i2} X_{2it} + \varepsilon_{it}$$

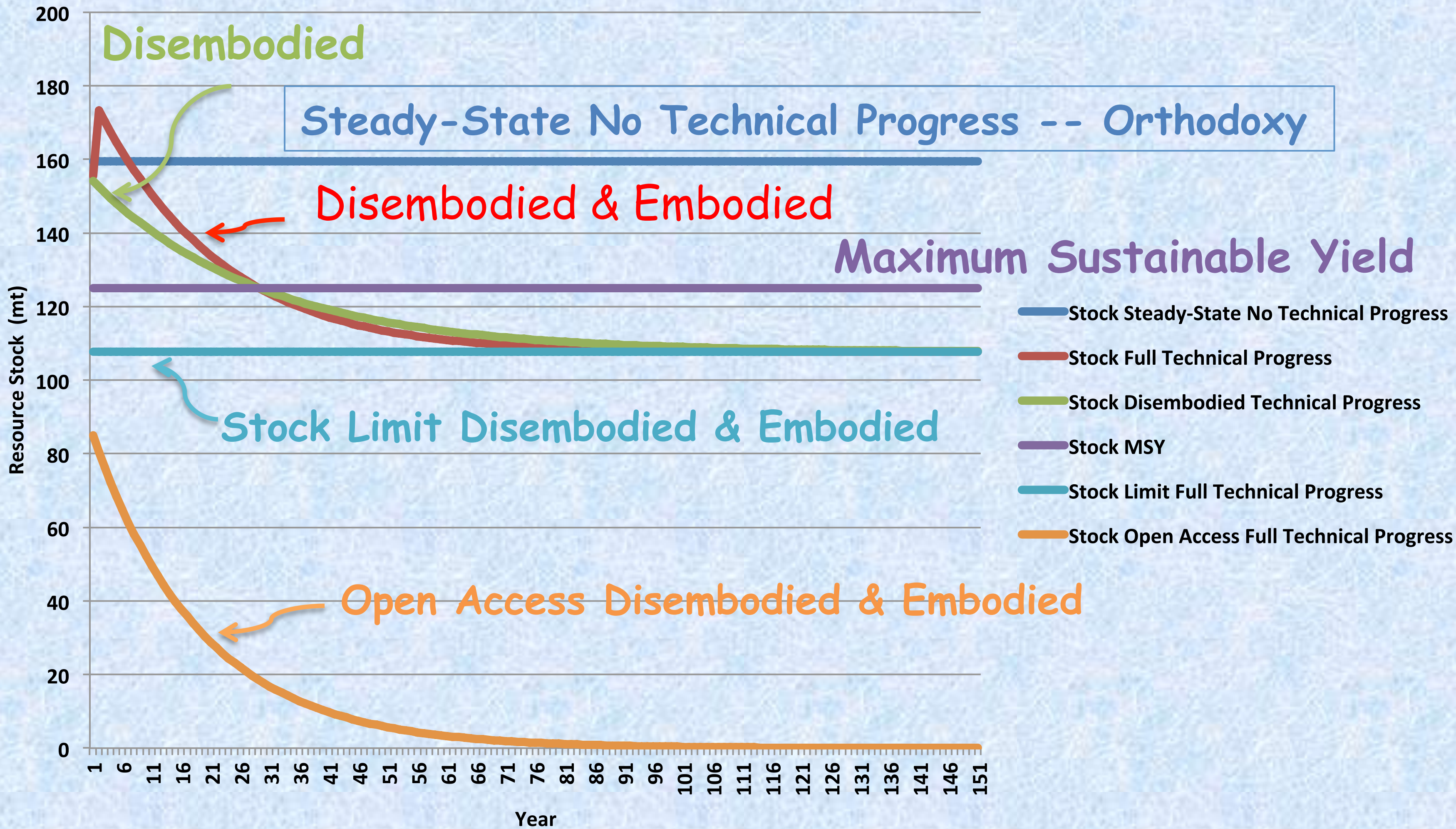
- Equivalent to Tornqvist index, Leontief-Sono separability (Fuss *J. Econometrics* 1977, Squires *Rand J. Econ.* 1984, *JEEM* 1987)
- Insert linear homogeneous translog effort aggregator function w/out intercept into production frontier.
- Index is subject to base period normalization (standard for quantity indices) (Fuss *J. Econometrics* 1977).
- No separability inflexibility.
- Hicks-neutral w. constant rate technical change due to limited obvs.
- Fixed effects counted on to address input endogeneity & selectivity bias.
- Nonetheless, two-stage least squares after Hausman test
- No serial correlation plus Huber-White robust s.e.
- Hypothesis tests (pseudo likelihood ratio tests) support $\beta_1 = 1$, $\beta_2 = 1$.

Parameters & Data

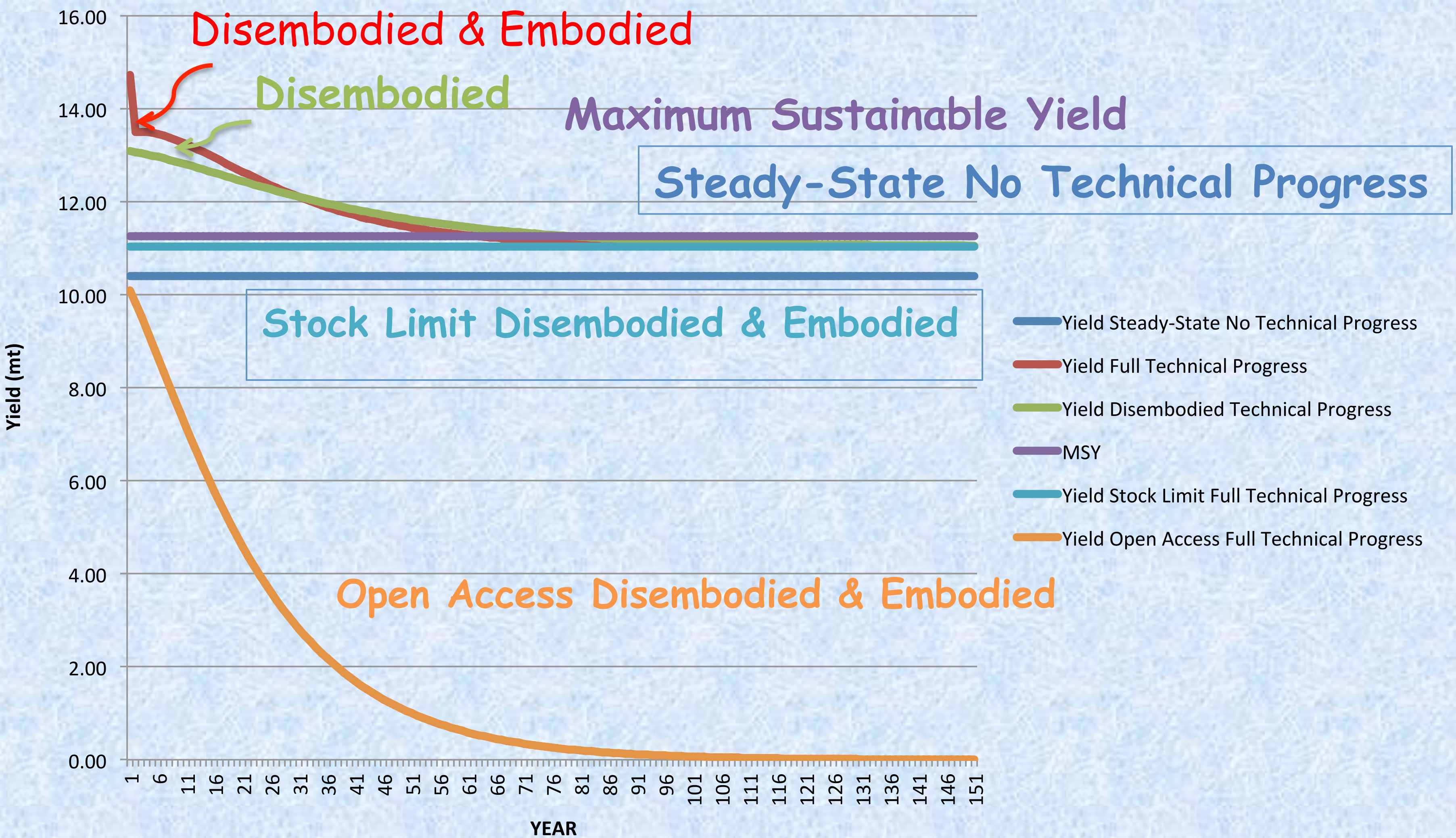
- λ = 3.91% per annum
- Total TFP= $\dot{T} = M_2\psi_t + \lambda$
  = 4.74%
- $\psi_t = [\dot{T} - \lambda]/M_2$ 1.80%
- M_2 = capital share = 0.46
- r = intrinsic growth rate = 0.18
- K = environmental carrying capacity 250 mt
- Data from international stock assessments and population biologists.

6. Empirical Results

Optimum Stock Size Over 150 Years

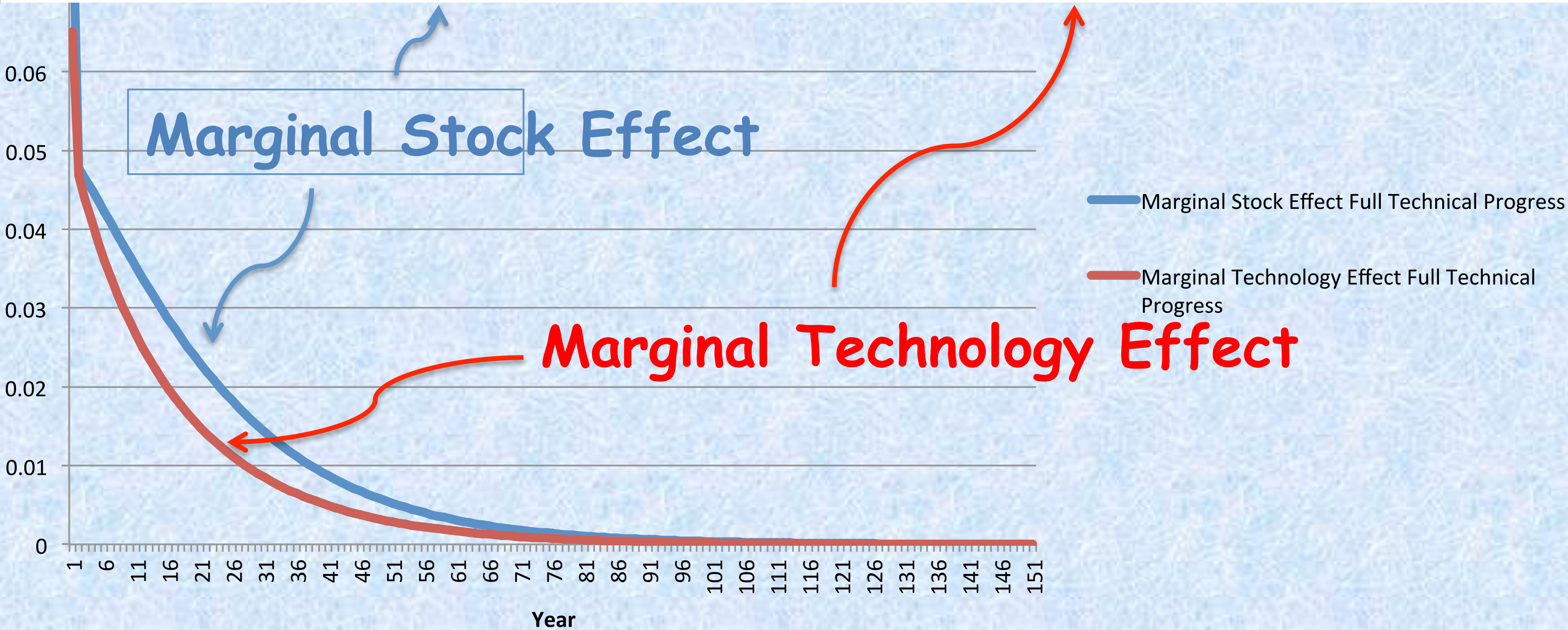


Optimum Yield Over 150 Years



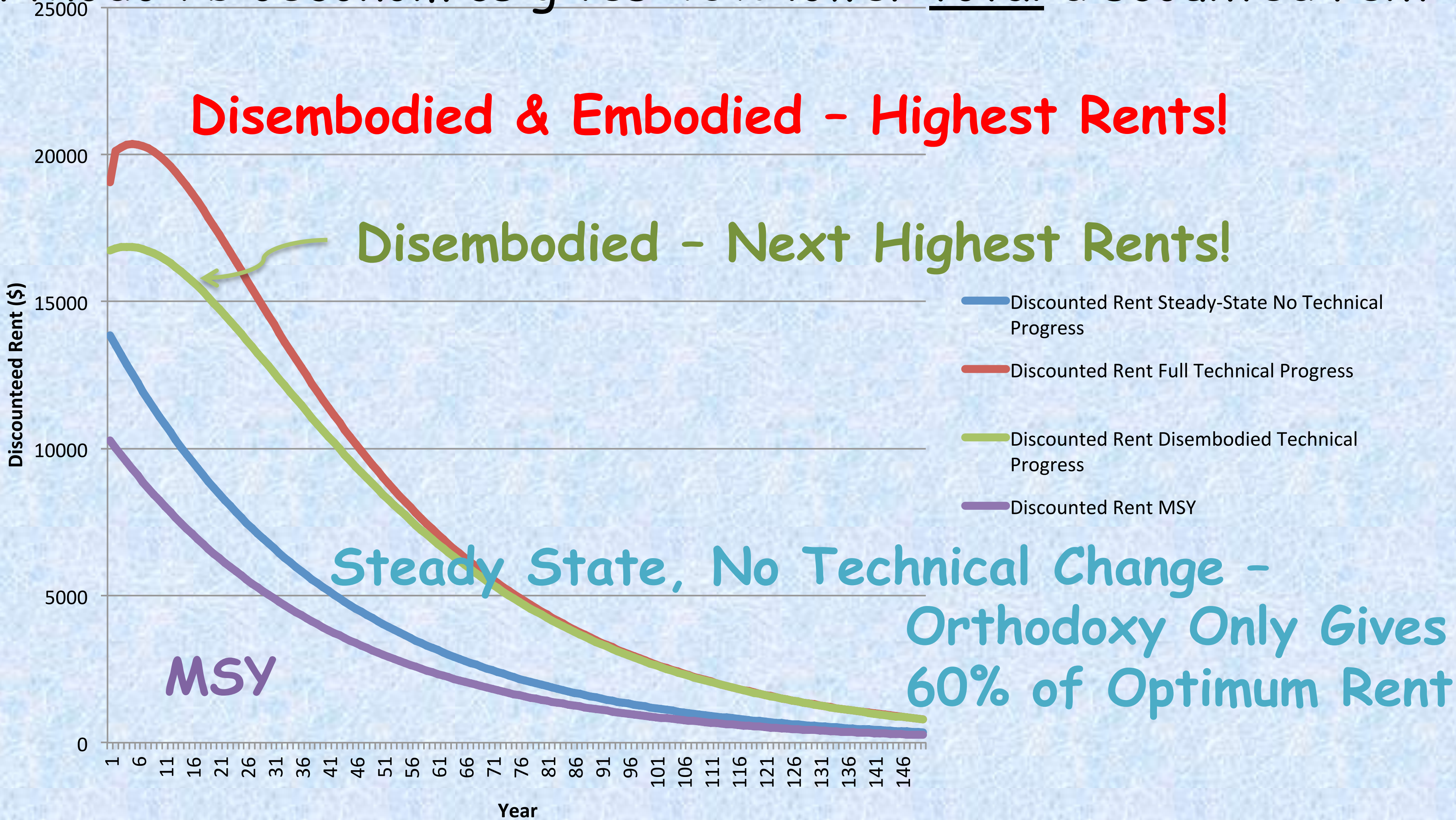
Marginal Stock & Technology Effects in Golden Rule

$$\frac{\partial F}{\partial S_t} + \frac{\left(c_v A + c_f(\gamma+\delta)\right) F(S_t)}{\left(PqAS_t e^{(\lambda+M_2\psi)t-\mu(t,Z)} - (c_v A + c_f(\gamma+\delta))\right) S_t} + \frac{\left(c_v A + c_f(\gamma+\delta)\right)(\lambda + M_2\psi - \partial\mu(t,Z)/\partial t)}{PqAS_t e^{(\lambda+M_2\psi)t-\mu(t,Z)} - (c_v A + c_f(\gamma+\delta))} = \delta.$$



Discounted Optimum Annual Rent

Orthodox bioeconomics gives 40% lower total discounted rent



7. Conclusions

Overfished stocks can be perfectly economically rational with technical change

- Technical change is perhaps the most important contributor to overfished stocks
- Perhaps more important than physical capital stock in natural units

Traditional Optimum is Scale Efficiency

- Traditional bioeconomic optimum is simply scale efficiency – ignores allocative & technical efficiency.

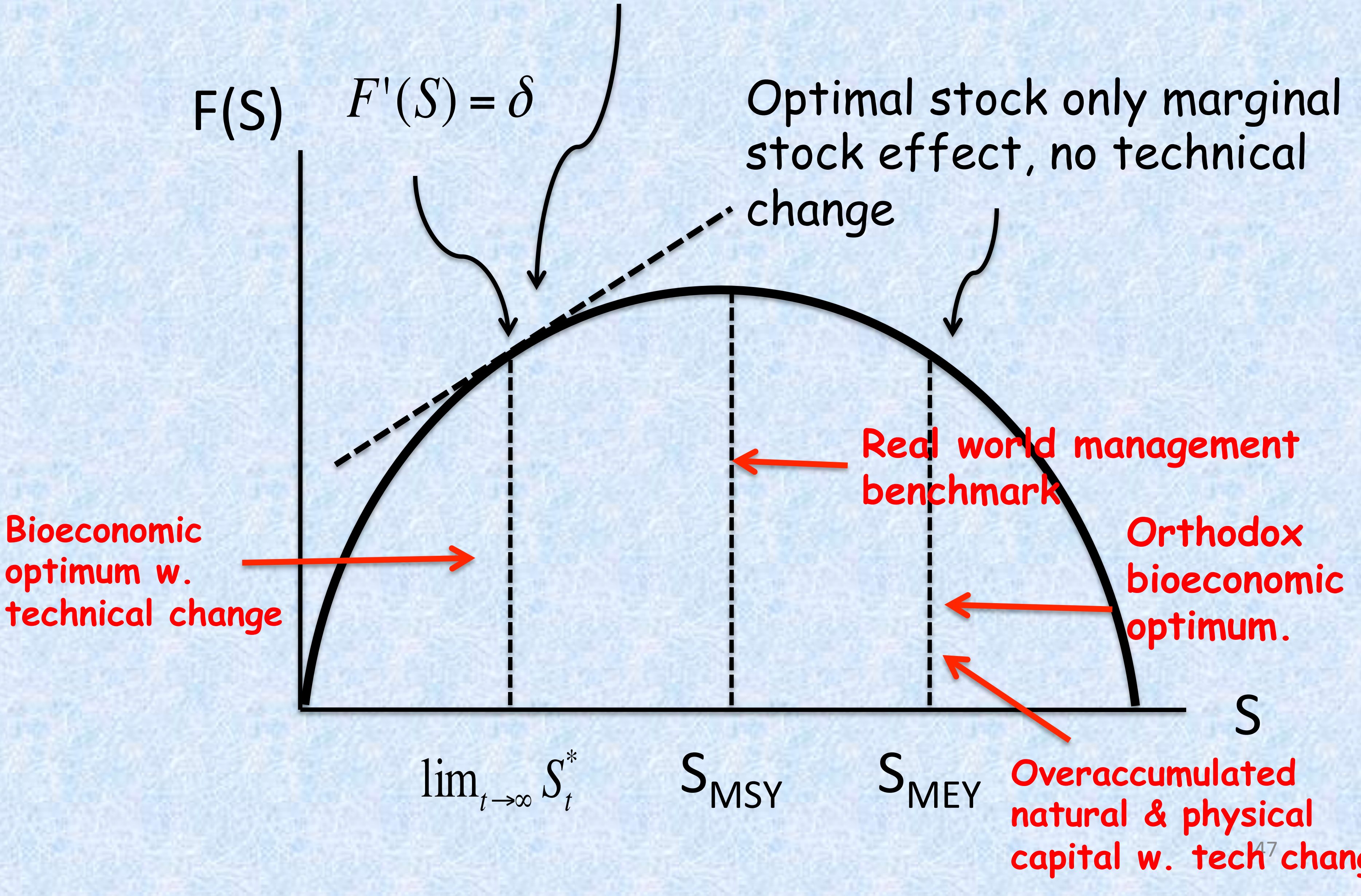
Steady-State Equilibrium Misleading

- Technical change is critical and overlooked in normative renewable resource economics
- Assumes static technology
- Assumes steady-state equilibrium.
- Creates opportunity cost of foregone rents by over-accumulated natural capital .

Traditional Normative Policy Could Be Economically Inefficent

- The present near-universal policy in global capture fisheries of managing for MSY (sometimes modified by a precautionary level) may in some instances be economically sub-optimal
- The policy surprisingly favors resource stocks too large rather than too small, over-saving and under-consuming through reduced harvests with excessive investment in natural capital, and can create a sizable opportunity cost of forgone rents.

Limit to optimal stock with both marginal stock effect and technical change over infinite time horizon



Modified Fundamental Equation of Renewable Resource Economics

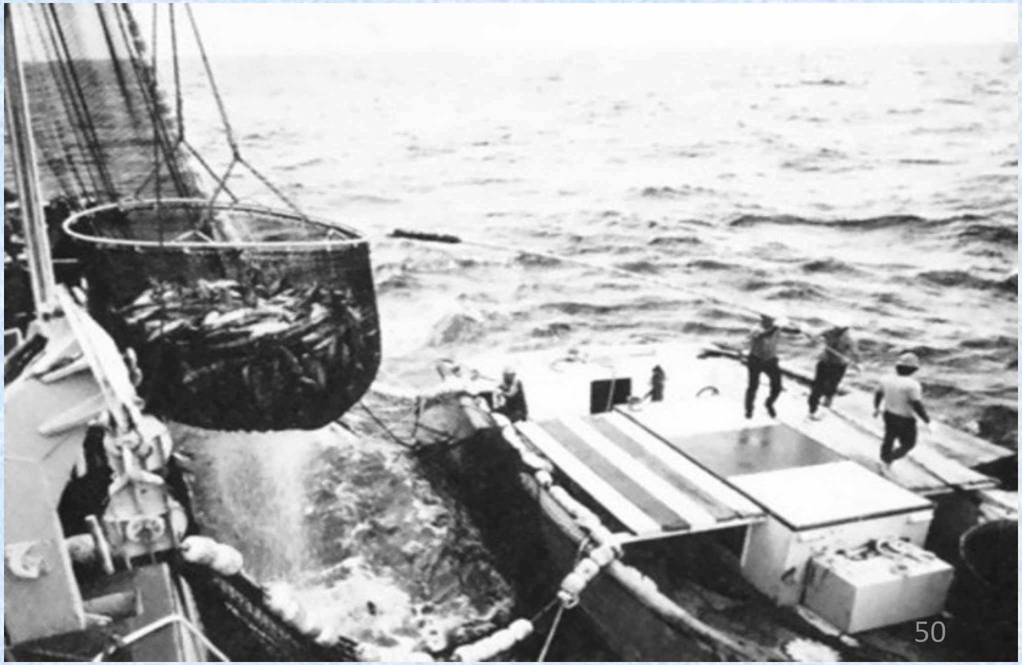
- Modified fundamental equation of renewable resource economics.
- Accounts for changes in state of technology and technical inefficiency.
- Pareto optimum stock is lower
  – And below MSY

Marginal Stock Effect is Marginalized

- Gains in technology and technical efficiency do the work of marginal stock effect in lowering costs of harvest.
- No longer need to keep fish in water to lower costs.

Output Focus for Mgmt

- Accounting for changes in technology and technical efficiency shifts management focus to output side.



Thanks! Questions?

With Technical Change and Only Private Costs and Benefits, Overfishing is Overstated

- Technical change is perhaps the most important contributor to overfished stocks
$$(S^* < S_{MSY})$$
- Some stocks thought currently overfished are not, purely on basis of maximizing economic rents from direct use values
  - Technical change dramatically lowers private costs
  - Minimal value of leaving fish in water to lower private costs