Fisheries management under correlated uncertainty: prices vs. quantities.

Chris Kennedy
University of Wyoming
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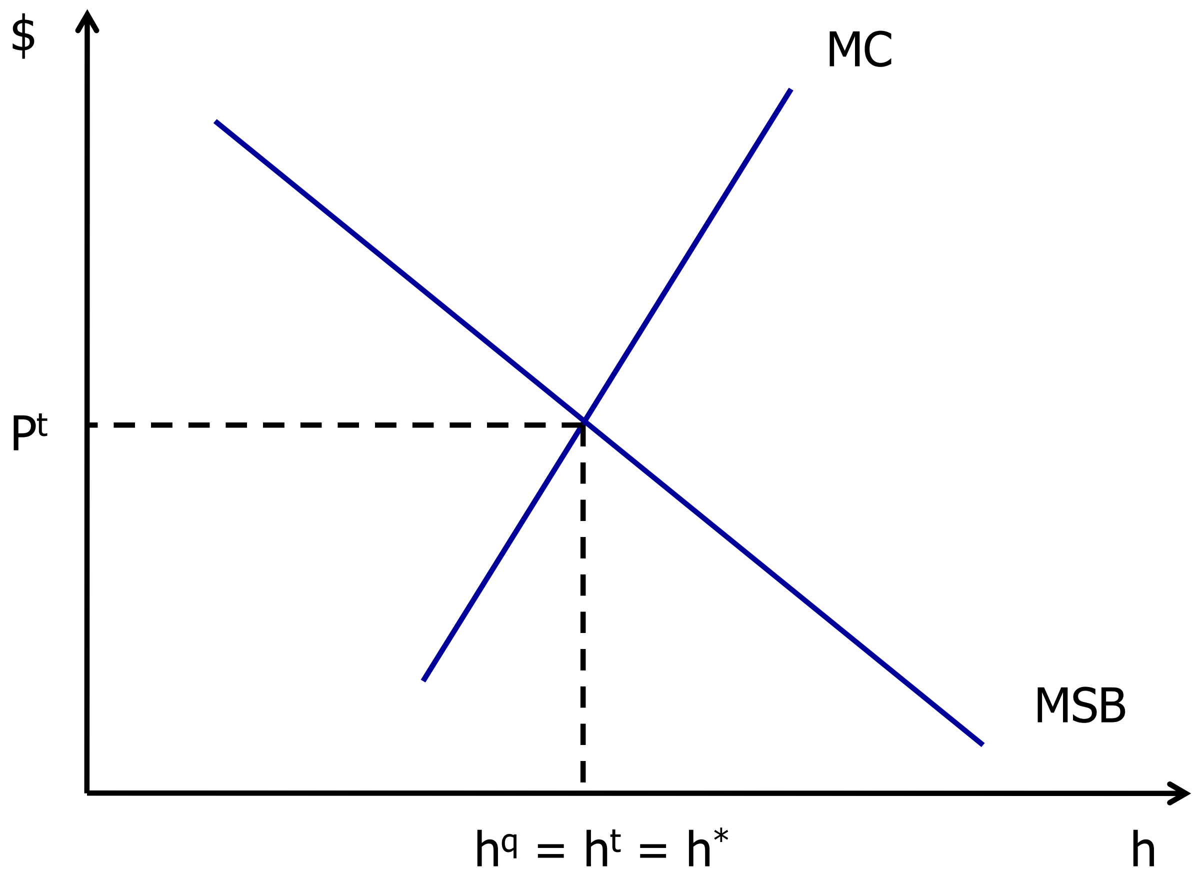
Current state of fisheries

- Worm, et al. (2006) – as of 2003, 27% of marine fisheries were "collapsed"
- Worm, et al. (2009) – "**Management actions** have achieved measureable reductions in exploitation rates… a significant fraction of stocks will remain collapsed unless there are further reductions"
- Effective management actions include (among others):
  - Effort controls (days-at-sea (DAS))
  - Harvest controls (individual transferable quotas (ITQs))
- This research looks at these two mechanisms in addition to landing taxes

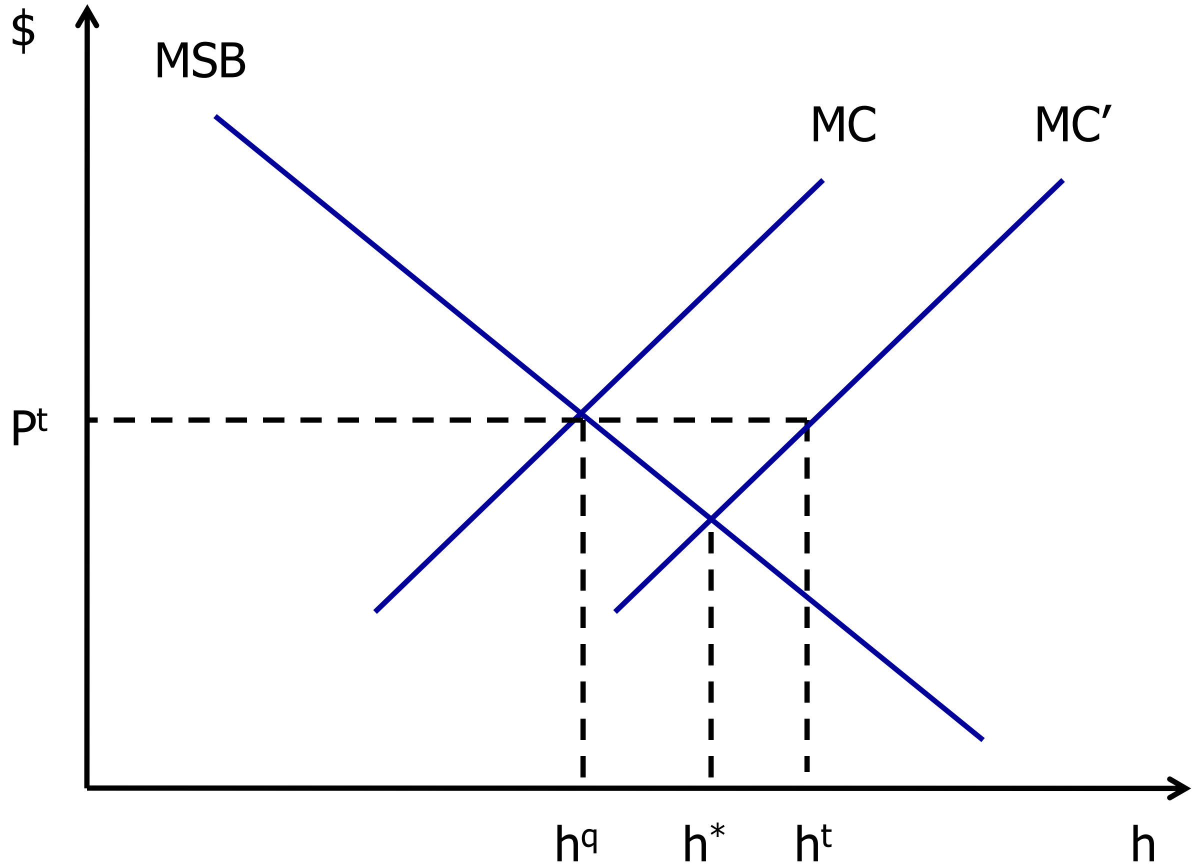
Literature review – harvest control mechanisms

- Most research – stochastic biological growth and/or stock uncertainty (Weitzman 2002)
- Majority of papers include at least one additional uncertain element
  - **CPUE** (Danielsson 2002, Hannesson and Kennedy 2003, Anderson 1986, Androkovich and Stollery 1991)
  - **Demand** (Hannesson and Kennedy 2003, Androkovich and Stollery 1991)
  - **Benefits** (Jensen and Vestergaard 2003, Anderson 1986)
  - **Enforcement** (Hansen 2008)
- This research will focus on stochastic biological growth and CPUE

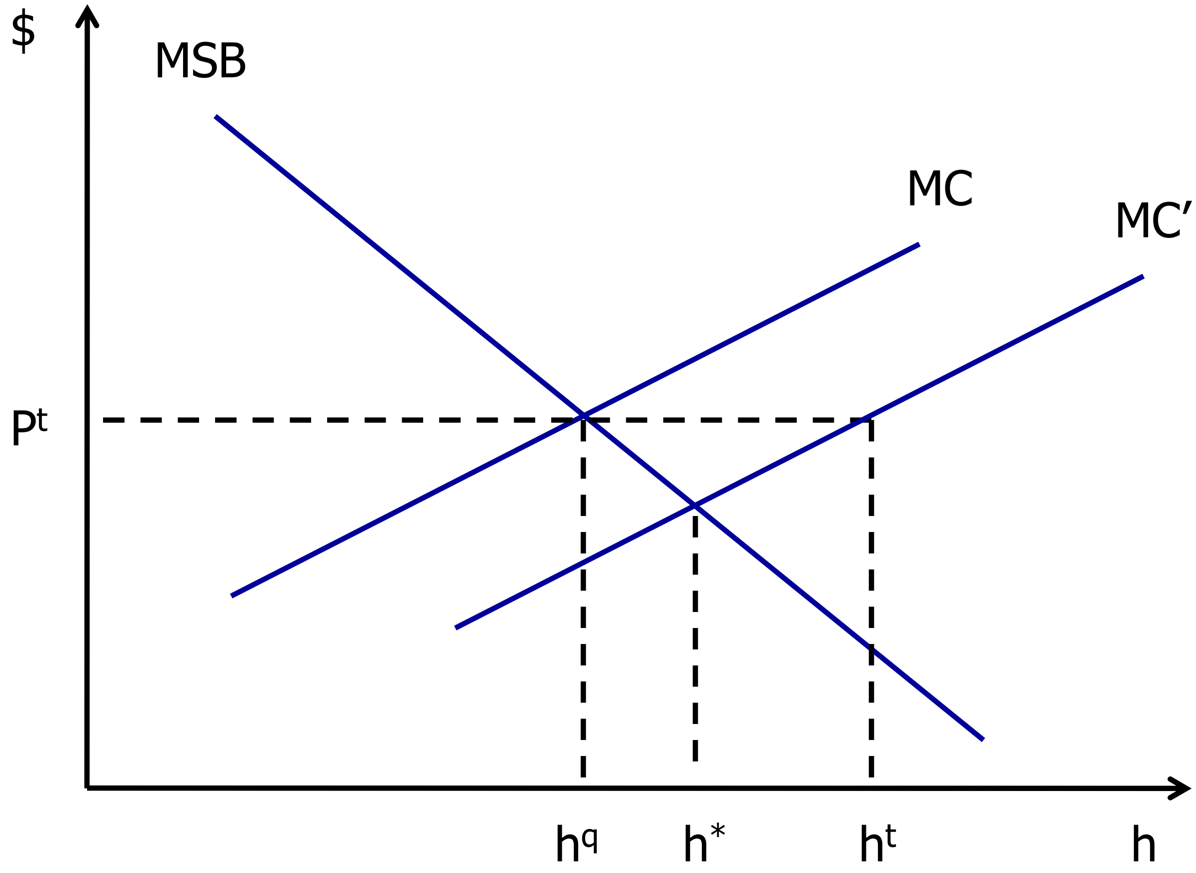
Taxes or harvest quotas?



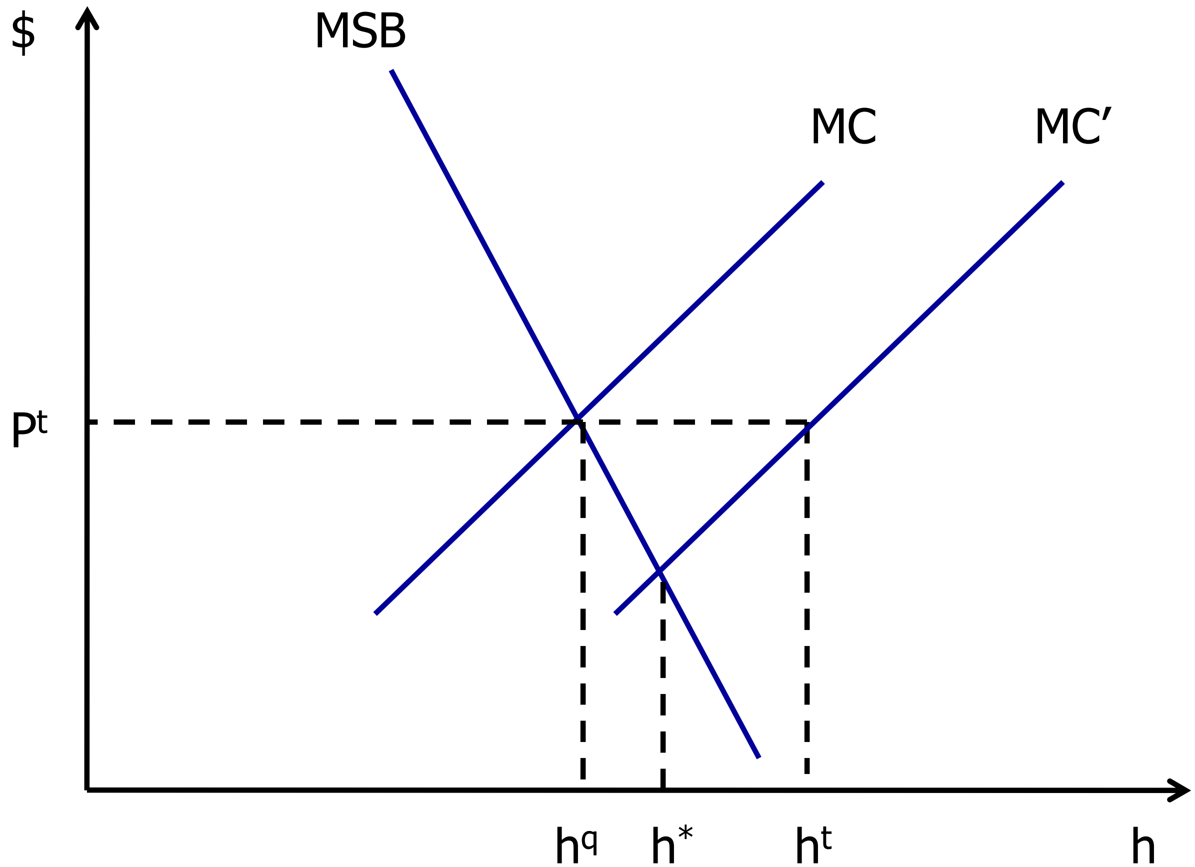
Uncertainty in CPUE



Shallow MC curve



Steep MSB curve



Motivation for this research

- Previous research has assumed that stochastic elements affecting biological growth and CPUE are independently distributed.
- This is unrealistic for a variety of commercially exploited fish species in which correlated deviations are observed, often associated with a single environmental variable.
- If stochastic elements are correlated, what does that imply for the choice between landing fees, effort limits, and harvest quotas?

Species	Driver	Effect of driver on CPUE (t)	Effect of driver on Growth (t)	Correlation (CPUE-Growth)
Blue crab	Decreased river flow	+	—	—
H. mackerel	SST	+	—	—
Albacore	El Niño	—	—	+
Bigeye	El Niño	+	+	+
Skipjack	El Niño	—	+	—
Yellowfin	El Niño	+	+	+

Table 1. Sample of fisheries exhibiting correlated uncertainty

Positive correlation – marginal private costs of fishing and marginal social benefits of escapement move concurrently

Negative correlation – marginal private costs of fishing and marginal social benefits of escapement move countercurrently

Prices vs. quantities under correlated uncertainty

- Wietzman (1974) – footnote explores the possibility that stochastic benefits and costs may be correlated
- Stavins (1996) – expands on the footnote
  - Shows conditions under which choice of taxes or quotas might be reversed
  - Pollution control is the backdrop
  - Example: urbanization increases costs and benefits of pollution control
- Shrestha (2001) – considers the performance of a non-linear tax under correlated uncertainty between benefits and costs of pollution control

A model of correlated uncertainty in fisheries

- Hybrid of Danielsson (2002) and Weitzman (1974)

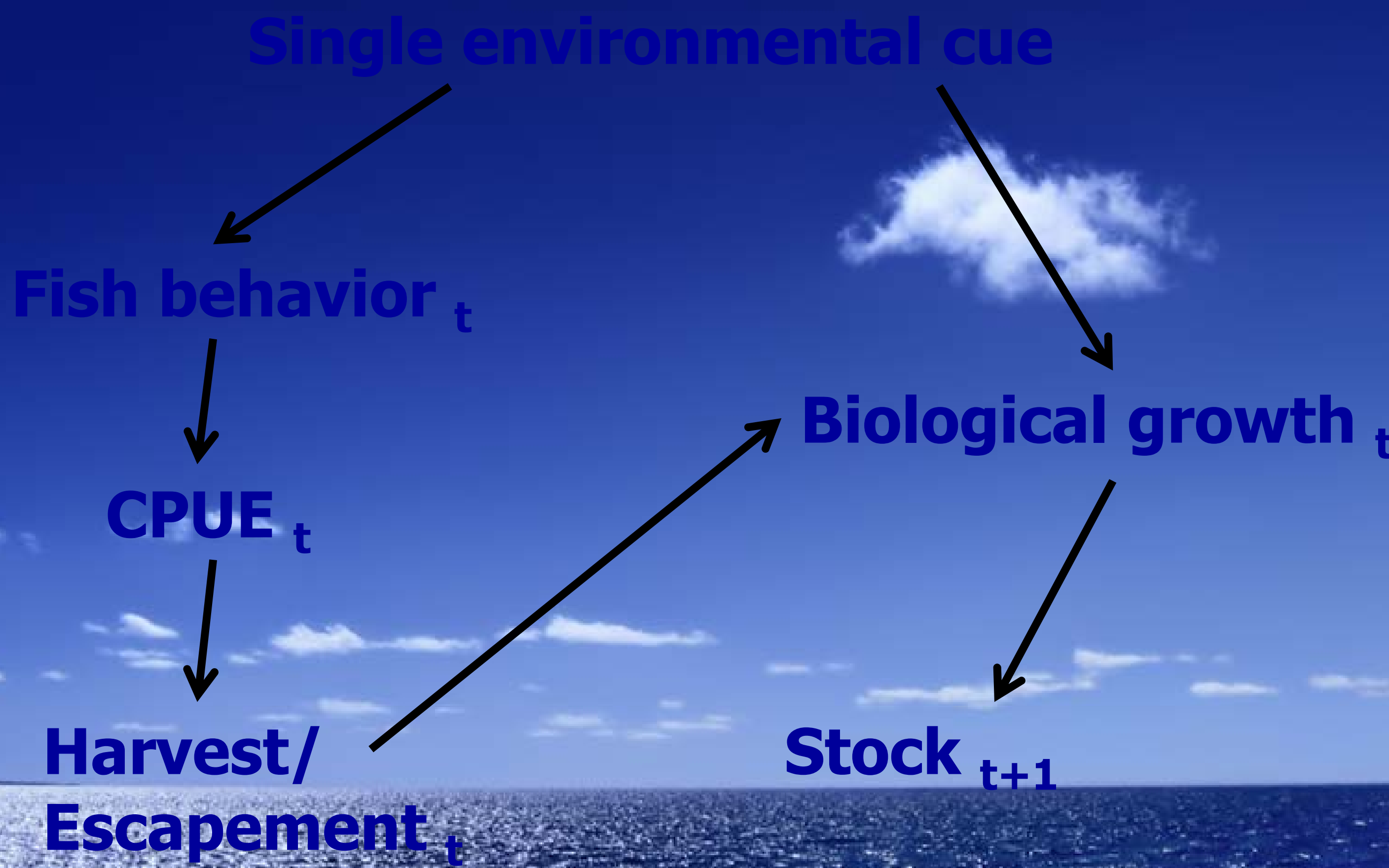
- Two uncertain elements
  - "effective biomass" due to fish behavior -> CPUE
  - "effective escapement" -> growth at the end of the period

- Observing the current stock, the regulator must choose a harvest control mechanism
  - Harvest quota with tradable rights, h^q
  - Effort quota with tradable rights, $\hat{e}$
  - Landing tax, τ

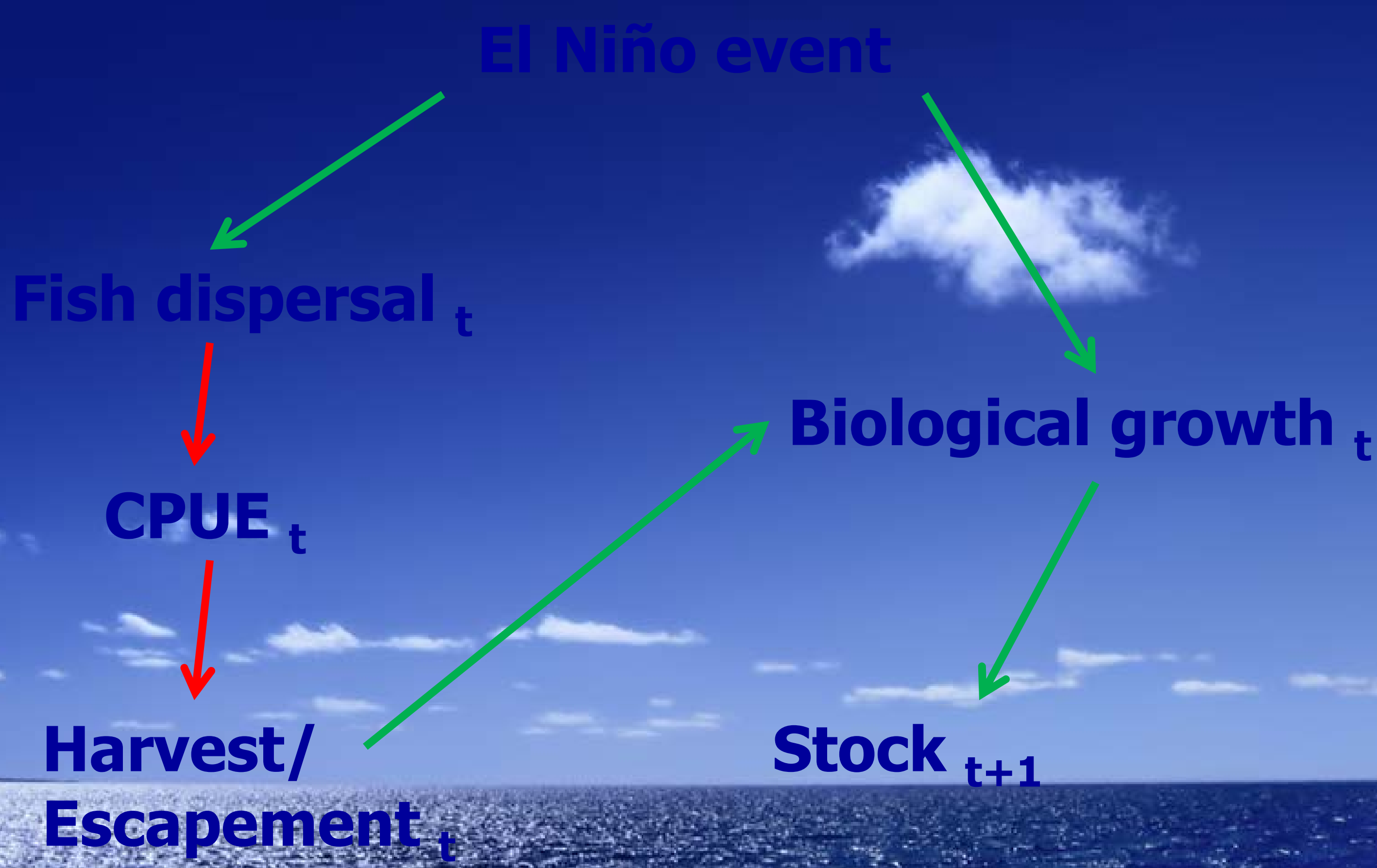
- Quotas are binding and efficiently distributed

- Fishermen observe "effective biomass" upon commencement of fishing

Conceptual model - correlation



Example – skipjack tuna, western Pacific



Model structure

- Regulator is charged with maximizing expected profits over an infinite number of periods

$$\sum_{t=1}^{\infty} \delta^{t-1} E\left[R(h_t) - C(e(h_t, S_t + \theta_t))\right]$$

$$\text{Subject to : } \quad S_{t+1} = F(S_t - h_t + \eta_t)$$

- Revenue *R(.)* is a concave function of harvests. Cost *C(.)* is a convex function of effort, where $e_h>0$, $e_{hh}>0$, $e_S<0$, $e_{Sh}=0$. *F(.)* is the density dependent growth function, $F_S>0$, $F_{SS}\leq 0$

- θ is an additive, stochastic variable dictating the "effective biomass", or the biomass observed by fishermen. $E[\theta]=0$, variance σ_θ^2

- η is an additive, stochastic variable dictating the "effective escapement", and thereby biomass available in period $t+1$. $E[\eta]=0$, variance σ_η^2

- The co-variance between θ and η is denoted by $\sigma_{\eta\theta}^2$

Model structure

- The Bellman equations for the three mechanisms are

$$V^{q}(h^{q},S)=\max_{h} E[R(h^{q})-C(e(h^{q},S+\theta))+\delta V^{q}(F(S-h+\eta))]$$

$$V^{e}(\hat{e},S)=\max_{e} E[R(q(\hat{e},S+\theta))-C(\hat{e})+\delta V^{e}(F(S-q(\hat{e},S+\theta)+\eta))]$$

$$\begin{aligned}V^{\tau}(\tau,S)=\max_{\tau} E[R(v(\tau,S+\theta))-C(e(v(\tau,S+\theta),S+\theta)\\ +\delta V^{\tau}(F(S-v(\tau,S+\theta)+\eta))]\end{aligned}$$

- In the spirit of Weitzman (1974), the relative superiority of instrument *i* over instrument *j* is given by

$$\Delta^{ij}=E[V^{i}(.)-V^{j}(.)];\ i,j=q,e,\tau;\ i\neq j$$

- **Critical assumption:** the amount of uncertainty in effective biomass and effective escapement is small enough to justify a 2nd order Taylor approximation of the effort, harvest, cost, revenue, biological growth, and value functions in the range that h^e and h^τ (e^q and e^τ) vary around h^q ($\hat{e}$)

Results – no correlation

- A degenerate distribution for θ implies that all instruments are equivalent; differences increase with $\sigma_\theta{}^2$

- The range for which effort quotas are the preferred instrument is relatively small and decreases with the slope of the marginal cost function

- Preference for harvest quotas over taxes and effort quotas
  - increases with the curvature of the value function
  - increases with the curvature of the growth function
  - decreases with the slope of the marginal cost function
  - decreases with the discount rate

- Uncorrelated case -> η does not matter (Stavins 1996)

Results – correlation

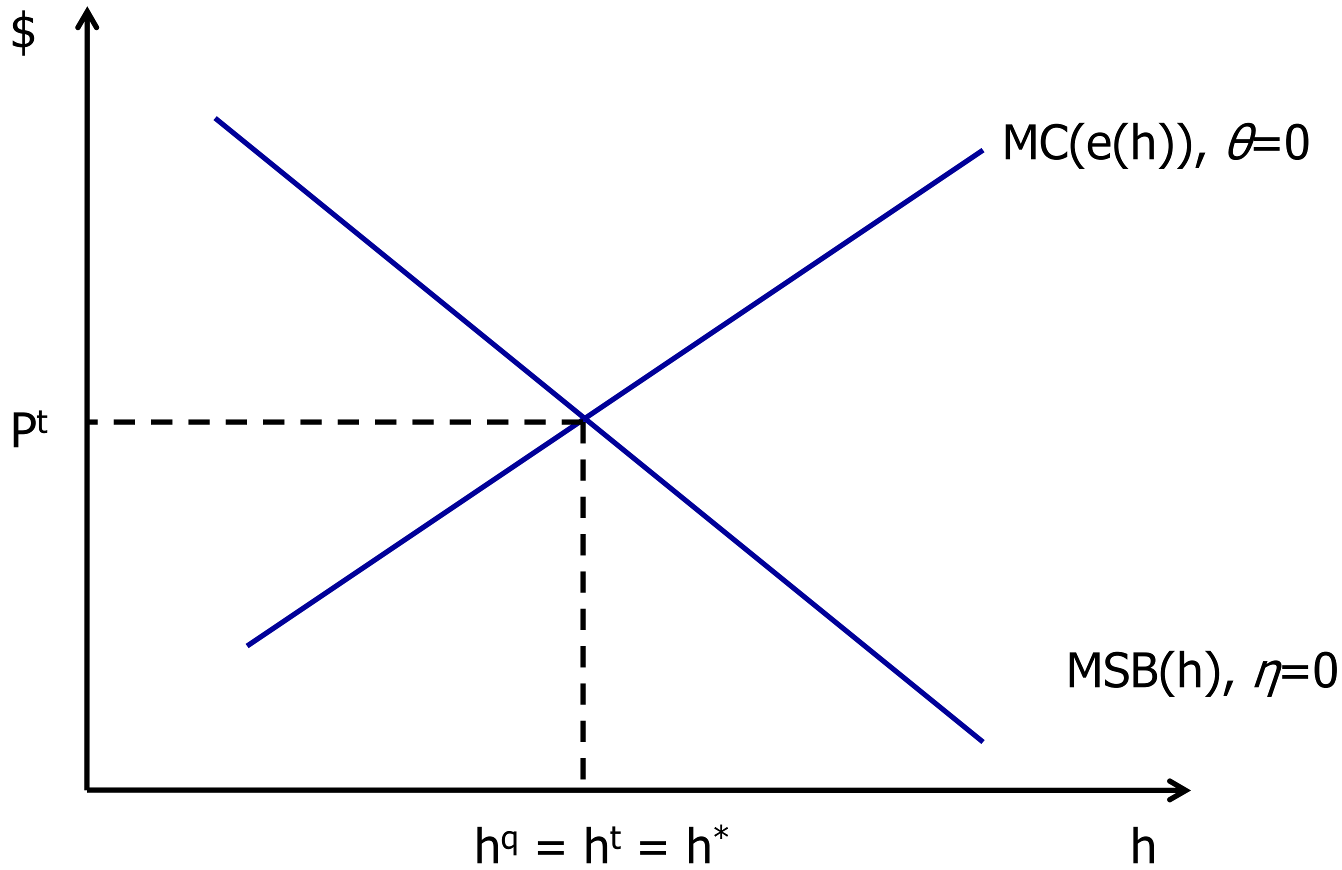
- Stochastic η is relevant when correlation exists

- Positive correlation tends to favor the tax over effort quotas and effort quotas over harvest quotas, and vice versa

- The impact of correlation
  - increases with the curvature of the value function
  - increases with the curvature of the growth function
  - increases with $\sigma_\theta{}^2$ and $\sigma_\eta{}^2$
  - decreases with the slope of the marginal cost function
  - decreases with the discount rate

- Effort quotas are never the *worst* mechanism under uncertainty, correlated or otherwise

Example – Negative correlation (Skipjack tuna, El Niño event)



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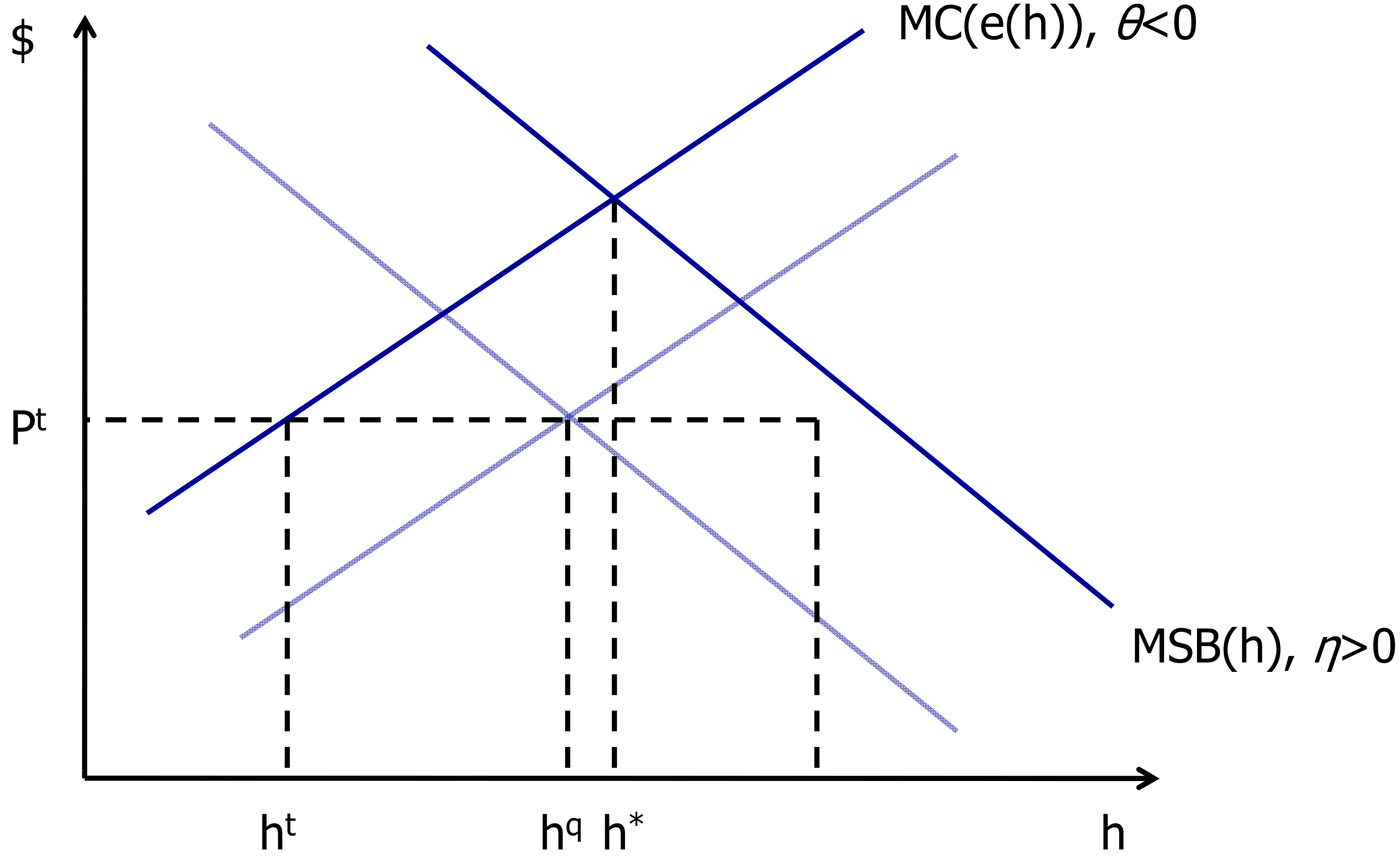

Is correlation likely to matter?

- It has been argued the slope of the marginal cost of effort in a fishery is relatively shallow
  - will tend to favor harvest quota control, but
  - increases the impact of correlation
  - if positive correlation exists, but is unaccounted for, this can lead to the wrong choice
- Negative correlation is especially problematic. If CPUE increases when biological growth is being negatively impacted, risk of collapse increases
  - Northern cod
  - Georgia blue crab
- Even if the mechanism for correlation is not apparent, strong empirical evidence can inform mechanism choice

Questions?