When fisheries management may increase uncertainty

Patrice Guillotreau, MARBEC, IRD, Sète, France
Joao Bosco Ribeiro do VaL, University of Campinas, Sao Paulo, Brazil
Elimane Kane, IMROP, Nouadhibou, Mauritanie
Jules Selles, MNHN, Paris, France
Thomas Vallée, LEMNA, Nantes University, Nantes, France

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2. The CVIU approach
(*Control Variation Increases Uncertainty*)

3. Numerical application

1. Sources of uncertainty in Fishery bioeconomic models

- Random fluctuations from environmental variability (Francis & Shotton 1997)

- Wrong parameter estimates and stock assessment errors (Sethi et al. 2005), structure of models (Hill et al. 2007)

- Structural uncertainty about the fishery system (IUU, compliance with quotas, economic data, demand system, technical change,…) (Squires & Vestergaard 2013, Wiedenmann and Jensen 2018)

→ Implications for fishery management (Reed 1979, Clark and Kirkwood 1986, Charles 1998, Sethi et al. 2005, Fulton et al. 2011)
→ Analogy with the Brainard principle adopted by a central bank (Brainard 1967)

Uncertainty may come from what other users will do…

The case of fishing agreements: the tradeoff between own fishing and selling fishing rights between LDC and DWFN countries

Fishwar model (Levhari & Mirman 1981)

Country 1's preference for the future

$$U_1 = \log x_1 + \beta_1 \log(Q - x_1 - x_2)^{\tau} \qquad (1)$$

Catch by country 1

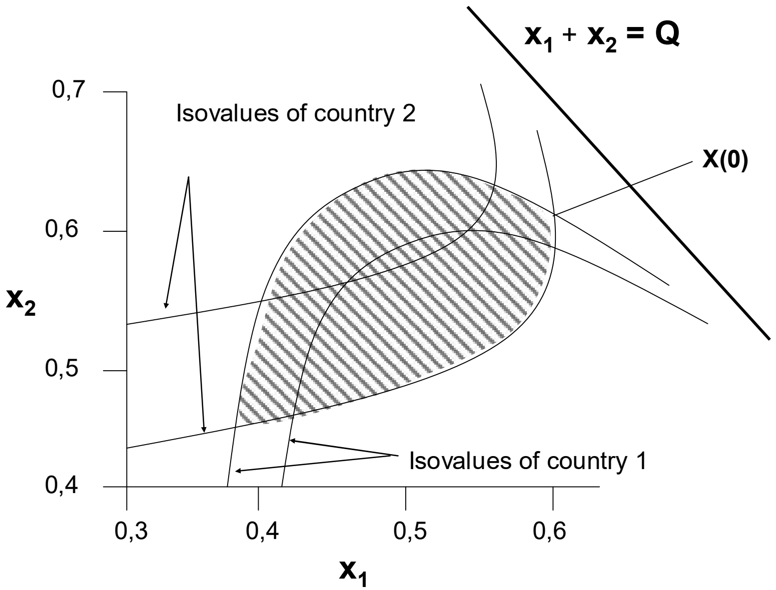
T.A.C.

Catch by country 2

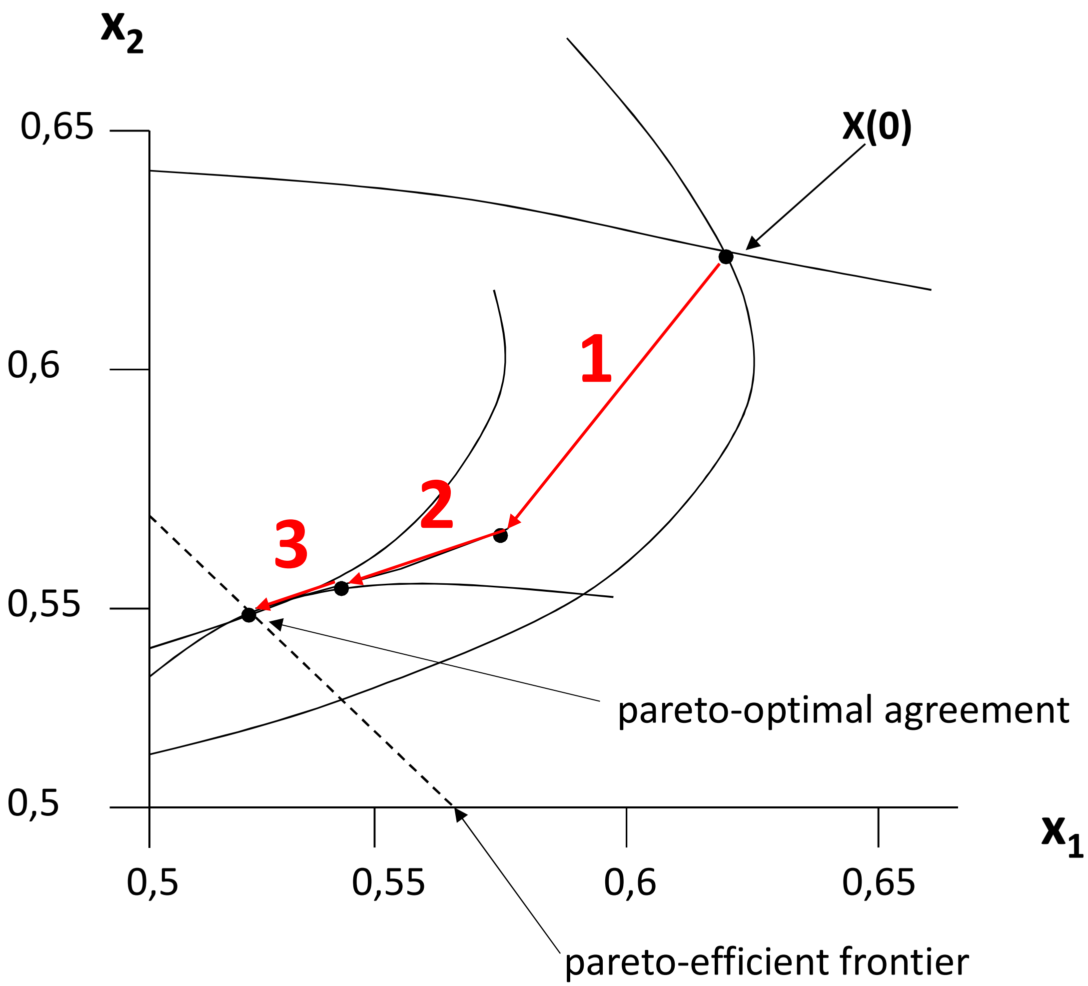
A couple of catches $x^{'} = (x_1^{'}, x_2^{'})$ dominates another couple $x = (x_1, x_2)$ if and only if $U_i(x^{'}) \geq U_i(x)$ and $U_j(x^{'}) > U_j(x)$, $\forall j \neq i$.

Such a couple is weakly Pareto optimal.

Bargaining area between the isovalue curves



Small step bargaining process



Ehtamo et al. 1999

Introduction of a macroeconomic dependence term (ex. EU DWFN *vs* LDC's income from selling or leasing fishing rights) (Vallée-Guillotreau-Kane 2009)

EU utility function:

$$U_{EU} = \log((1 - \alpha_{LDC})x_{EU}) + \beta_{EU} \log(Q - x_{EU} - x_{LDC})^{\tau} \qquad (2)$$

LDC utility function:

$$U_{LDC} = \log(x_{LDC} + \alpha_{LDC} x_{EU}) + \beta_{LDC} \log(Q - x_{EU} - x_{LDC})^{\tau} \qquad (3)$$

with $0 \leq \alpha_{LDC} < 1$; $0 < \beta_{EU}, \beta_{LDC} \leq 1$; $0 < \tau < 1$; $0 < Q < +\infty$,
and with

$$(x_{EU}, x_{LDC}) \in D = \{(x_{EU}, x_{LDC}) : x_{EU} \geq 0, x_{LDC} \geq 0, x_{EU} + x_{LDC} \leq Q\} \qquad (4)$$

$\Rightarrow \alpha_{LDC} x_{EU}$ is the EU transfer to LDC (e.g. the subsidy is proportional to the catches).

Introduction of a macroeconomic dependence (LDC's income from leasing fishing rights)

The Nash equilibrium is defined by

$$\begin{cases} x_{EU}^{N} = \frac{Q\beta_{LDC}}{\beta_{EU}(1+\beta_{LDC}\tau)+\beta_{LDC}(1-\alpha_{LDC})},\ x_{LDC}^{N} = \frac{Q(\beta_{EU}-\alpha_{LDC}\beta_{LDC})}{\beta_{EU}(1+\beta_{LDC}\tau)+(1-\alpha_{LDC})\beta_{LDC}}, \\ \quad \text{if } \alpha_{LDC} < \frac{\beta_{EU}}{\beta_{LDC}} \\ x_{EU}^{N} = \frac{Q}{1+\tau\beta_{EU}} \text{ and } x_{LDC}^{N} = 0,\ \text{if } \alpha_{LDC} \geq \frac{\beta_{EU}}{\beta_{LDC}} \end{cases}$$

At the equilibrium, there is a condition allowing the LDC to fish:

$$\alpha_{LDC} < \frac{\beta_{EU}}{\beta_{LDC}}$$

If this condition holds, it can be demonstrated that:

$$\frac{\partial x_{EU}^{N}}{\partial \alpha_{LDC}} > 0 \text{ and } \frac{\partial x_{LDC}^{N}}{\partial \alpha_{LDC}} < 0$$

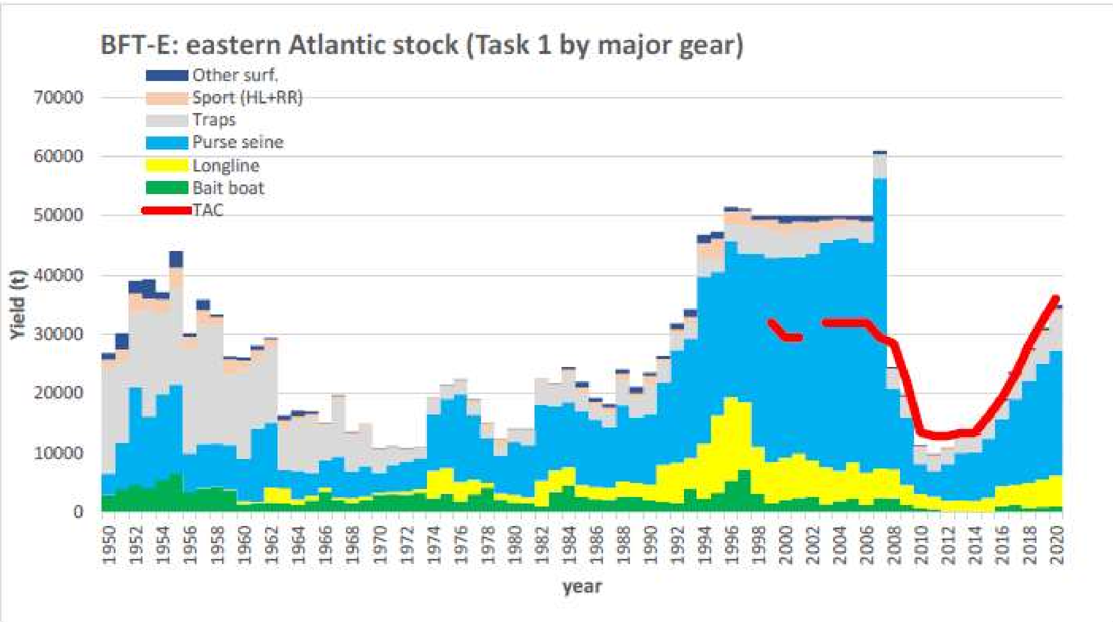
Results

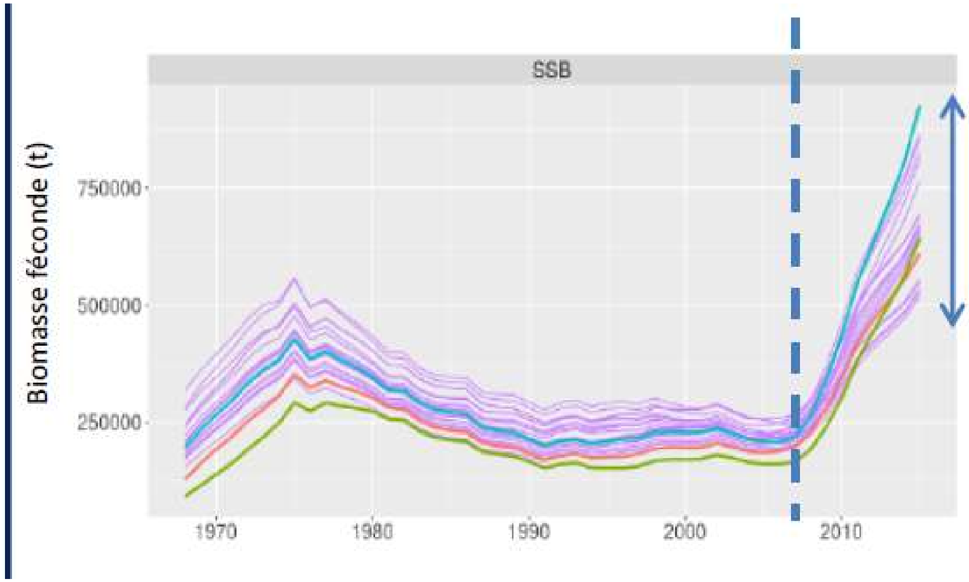
- The following outcomes can also be verified for EU:
  - If the EU preference for the future increases its catches diminish.
  - If the monetary transfer rate imposed by LDC increases, then the utility of EU is reduced.
  - If the preference for the future of LDC increases, then the utility of EU increases through the capacity to fish more + biomass increase.
- And for the LDC :
  - If the preference for the future of LDC increases its catches and utility diminish (not enough compensation from the transfer or from the long run component).
  - The utility of LDC increases with the transfer rate.

→ ***Extensions***: Nash *vs* Stackelberg (Vallée et al. 2009 – *REP*) + 3 players in a coalition game (Vallée & Guillotreau 2010 – *Environmental Economics*)

Many sources of uncertainty in fishery management: the Bluefin Tuna case (Selles 2018)

→ High degree of uncertainty (SSB, recruitment, catches, climate…), non-compliance, over-harvesting, IUU fishing, role of e-NGOs, variability of the TAC…





Source: Jules Selles (2018), Incertitude et gestion des pêcheries internationales : application au thon rouge de l'Atlantique, PhD Thesis, University of Nantes. ICCAT 2022.

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(From Jules Selles PhD)

Can the Threat of Economic Sanctions Ensure the Sustainability of International Fisheries? An Experiment of a Dynamic Non-cooperative CPR Game with Uncertain Tipping Point

Selles Jules[1] · Bonhommeau Sylvain[2] · Guillotreau Patrice[3] · Vallée Thomas[3]

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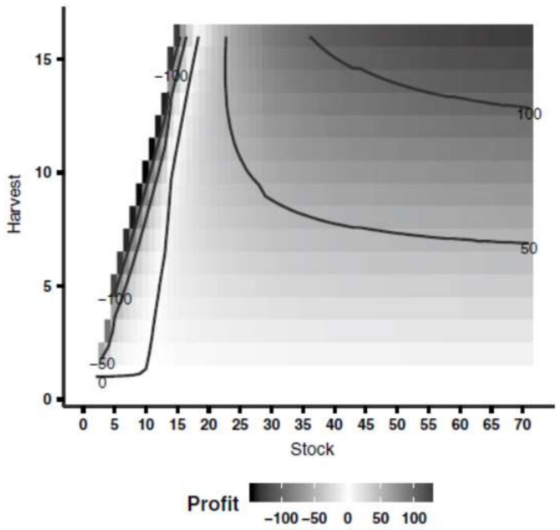


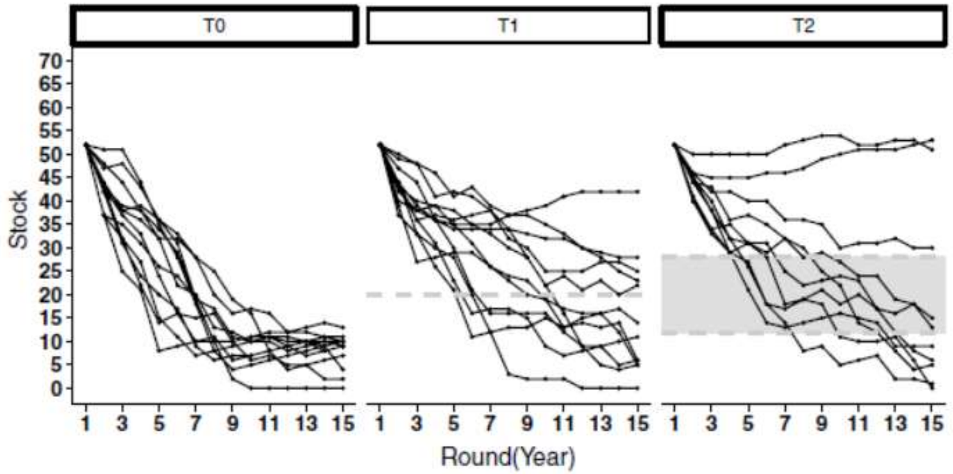


Fig. 3 Time series of resource stock size (biomass in units) by treatments (T0, T1 and T2). The grey dashed line corresponds to the threshold B_{lim} in T1 and the shaded area to the uncertainty range around the potential value of B_{lim} in T2

2. The CVIU approach (*Control Variation Increases Uncertainty*)

(do Val-Guillotreau-Vallée et al., EJOR 2019)

Bioeconomic model

$$\pi(h(t)) = ph(t) - ch(t)^2 \qquad (1)$$

$$h(t) = \text{TAC}(t) = h_e + u(t) \qquad (2)$$

→ $u(t) > 0$

→ $u(t) < 0$

$$\dot{z}(t) = az(t) + b - h(t) \qquad (3)$$

$$\dot{z} = (a + \epsilon_z)z(t) + (b + \epsilon_b) - h(t) = az(t) + b + (a\epsilon_z z(t) + \epsilon_b) - h(t) \qquad (4)$$

$$\dot{z}(t) = az(t) + b - (1 + \varepsilon_h)h(t) = az(t) + b - h(t) - \varepsilon_h h(t) \qquad (5)$$

$$\dot{z} = az(t) + b - h(t) + \underbrace{(a\epsilon_z z(t) + \epsilon_b - \epsilon_h h(t)) + \epsilon}_{\text{uncertainties}} \qquad (6)$$

uncertainties

CVIU Dynamics

$$dz(t) = G(z(t))dt - h(t)dt + \sigma dW(t), \quad t \geq 0, \qquad (7)$$

Change of variables: $x(t) := z(t) - z_e$ and $u(t) := h(t) - h_e$

Where z_e and h_e are desirable levels of biomass and catch, like the MSY levels.

$$\begin{aligned} dx(t) &= dz(t) = G\left(z_e + x(t), h_e + u(t)\right) dt + \sigma dW(t) \\ &\cong \left(A^0 x(t) + B^0 u(t)\right) dt + \sigma dW(t), \quad t \geq 0, \end{aligned} \qquad (8)$$

$$\begin{aligned} dx(t) = (Ax(t) + Bu(t))\, dt + \sigma dW(t) + (\bar{\sigma}_x + (\sigma_x^+ x(t)^+ - \sigma_x^- x(t)^-) dW^x(t) \\ + (\bar{\sigma}_u + (\sigma_u^+ u(t)^+ - \sigma_u^- u(t)^-) dW^u(t). \end{aligned} \qquad (9)$$

Optimization Problem: minimization of the expected cost function, given the dynamics (9):

$$E\Big[\int_0^T e^{-\alpha t}\left(-\pi(h_e, u_t) + x(t)^2 + qx(t)\right) dt\Big] \qquad (10)$$

With α a discount rate and *x(t)* the gap between a desired biomass level and the current stock level, and *qx(t)* a reward (*q<0*) or a penalty (*>0*) for achieving a greater biomass level.

→ TRADEOFF between increasing profits and reducing the gap.

MAIN RESULTS:

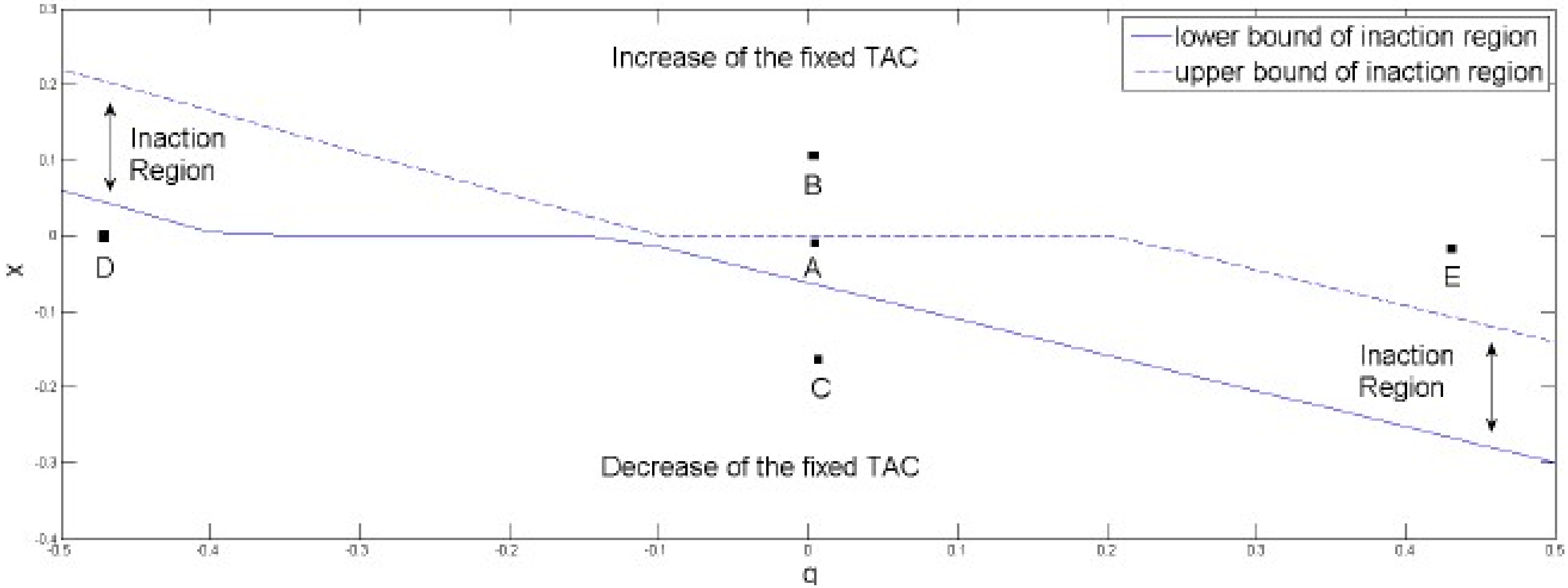
a) ***We derive the theoretical CVIU optimal solutions***
b) ***Conditions for existence and size of Inaction Regions are discussed***
c) ***Numerical solutions are provided to illustrate***

“With a poorly known dynamics of the fishery system, the CVIU approach points out the limit cases within which fishery managers should rather stick to a fixed management rule (e.g. TAC) instead of adapting it permanently to the latest state of knowledge surrounding stock assessment and harvest levels.”

3. Numerical application

$A = -0.2,\ \bar{\sigma}_x = \bar{\sigma}_u = 0.2,\ \sigma_x^+ = \sigma_u^+ = 0.3,\ \sigma_x^- = \sigma_u^- = 0.5.$

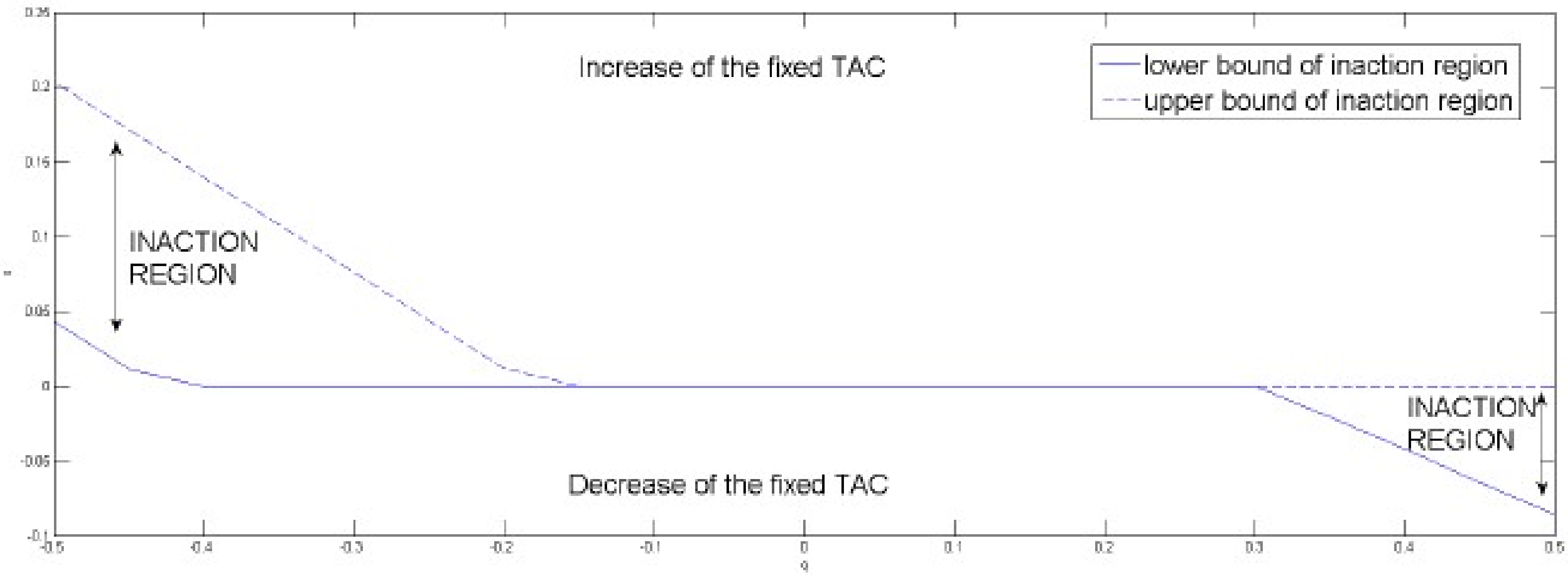
$\alpha = 0.9$



Position of the inaction region in the state x with respect to q (and α=0.9)

(reward when q<0 or penalty when q>0 if the biomass state is above the desired state)

$A = -0.2,\ \bar{\sigma}_x = \bar{\sigma}_u = 0.2,\ \sigma_x^+ = \sigma_u^+ = 0.3,\ \sigma_x^- = \sigma_u^- = 0.5.$ $\alpha = 0.2$



Position of the inaction region in the state x with respect to q (and α=0.2)

Discussion & conclusion

- The nature/source of uncertainty affects the effectiveness of management (e.g. how reliable is stock assessment?)

- We hypothesized that control in fishery management variations may increase the level of state uncertainty. The optimal feedback control policy may reveal an inaction region in a state space

- This inaction region depends on several conditions such as: state location w.r.t. desired level, discount rate, reward or penalty from being far from it (tradeoff between profits and stock, asymmetric multiplicative uncertainties) …

- Possible extension: empirical applications (how to measure the different types of uncertainties), connection to Management Strategy Evaluation (MSE) and Harvest Control Rules (HCR)

THANK YOU

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