Management solutions for shifting trans-boundary fish stocks under fixed catch shares

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Motivation

- Many fish stocks are already shifting northward driven by the warming seawater with implications for the fishing industry and the sustainability of the species.
- Distributional responses: in North Sea, two-thirds of the studied species; in the Atlantic European waters, ICES found distributional changes in 16 of the 21 key fish species analyzed.
- Existing trans-boundary fishery agreements emphasize the "stability" of quota shares.
- The EU Common Fisheries Policy allocates TACs among countries following the "relative stability concept", a key principle governing since 1970s. Once quota shares are allocated, it is almost impossible for member states to change them; e.g., 30% hake TAC for Spain.
- "Stability" is also emphasized in bilateral or multilateral fisheries negotiations: e.g., EU and non-EU countries.

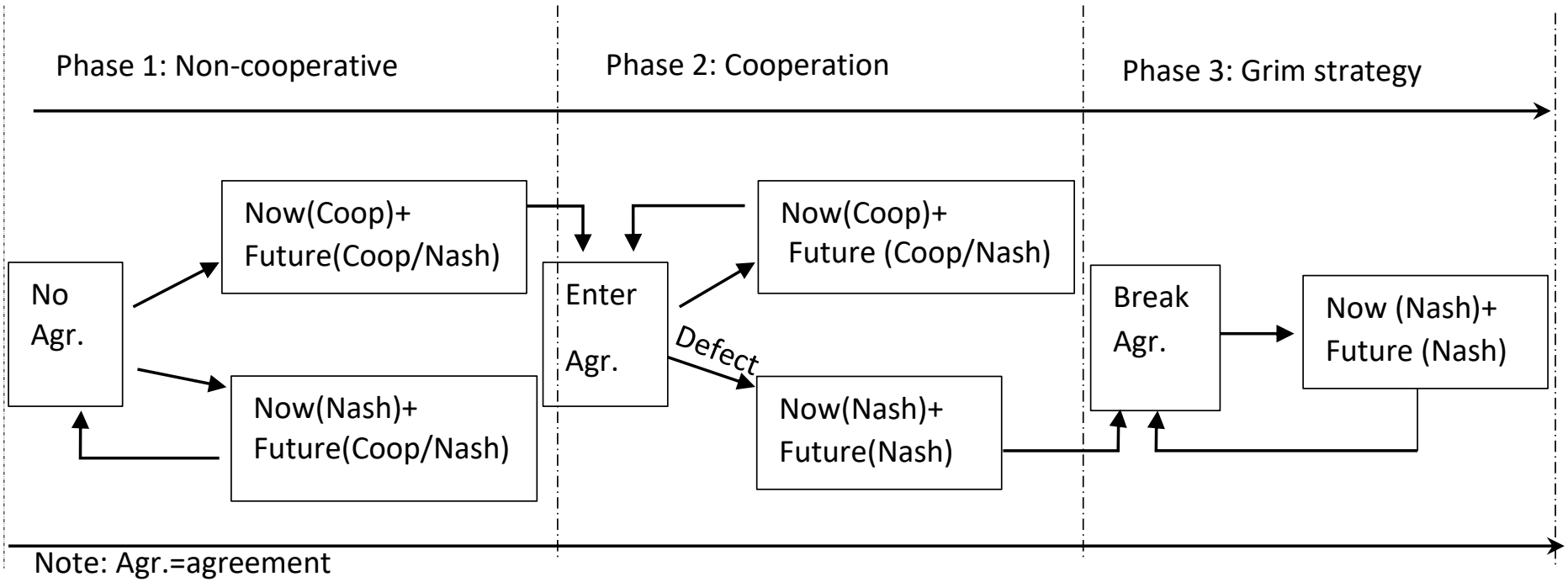
Motivation

- The relative stability principle is important especially for the fisheries industry—to ensure relatively stable cash flows.
- This policy choice implicitly accounts for utility components other than harvest profit, such as employment and supply chain.
- Against this background, it seems necessary to understand to what extent current management practice can be used to address the impacts of climate change.
- Specifically, we formulate a fixed catch share (FCS) scheme and we will see under what conditions the FCS can be used to manage shifting stocks and what are the benefits that we can expect.

Model: The rules

- Two-player game theoretical model, asymmetric stock ownership (θ).
- Self-enforcing fishery agreement.
- At each time step, a player can choose not to cooperate, cooperate, or defect.
- Players negotiated on a fixed catch share(FCS, σ) that remains unchanged for the entire agreement period.
- Grim strategy: once a player defects, non-cooperative game resumes.
- Allow benefit transfer (access right, monetary transfer) if a player is entitled more catch quota than he can catch optimally in his own water.

Model: The rules



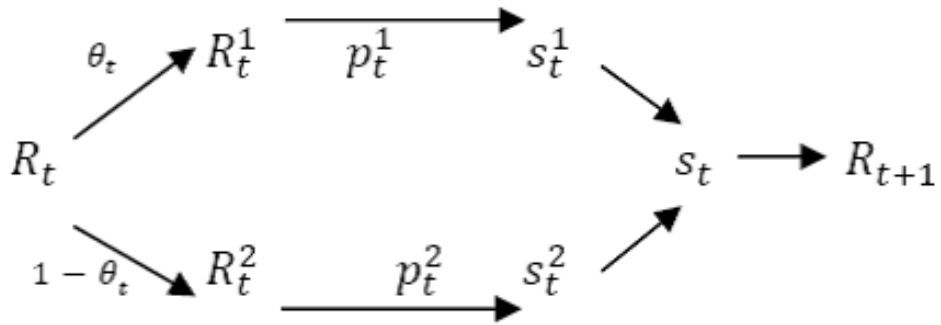
Examples of fisheries agreements

Year	Blue whiting	NSS herring	Mackerel
2000		NO+IS+FA+EU+RU	NO+FA+EU
2001		NO+IS+FA+EU+RU	NO+FA+EU
2002		NO+IS+FA+EU+RU	NO+FA+EU
2003		NO+IS+FA+EU+RU	NO+FA+EU
2004		NO+RU	NO+FA+EU
2005		NO+RU	NO+FA+EU
2006	NO+IS+FA+EU	NO+EU+RU	NO+FA+EU
2007	NO+IS+FA+EU	NO+IS+FA+EU+RU	NO+FA+EU
2008	NO+IS+FA+EU	NO+IS+FA+EU+RU	NO+FA+EU
2009	NO+IS+FA+EU	NO+IS+FA+EU+RU	NO+FA+EU
2010	NO+IS+FA+EU(+RU)	NO+IS+FA+EU+RU	NO+EU
2011	NO+IS+FA+EU(+RU)	NO+IS+FA+EU+RU	NO+EU
2012	NO+IS+FA+EU(+RU)	NO+IS+FA+EU+RU	NO+EU
2013	NO+IS+FA+EU(+RU)	NO+IS+EU+RU	NO+EU
2014	NO+IS+FA+EU(+RU)	NO+IS+EU+RU	NO+EU
2015			NO+FA+EU
2016	NO+EU	NO+EU	NO+FA+EU
2017	NO+EU	NO+EU	NO+FA+EU

Note: NO=Norway; IS=Island; RU=Russia; FA=Faroe

Spatial distribution shift

- "Split stream" migration pattern: a migratory stock moves between spawning and fishing grounds of two countries.



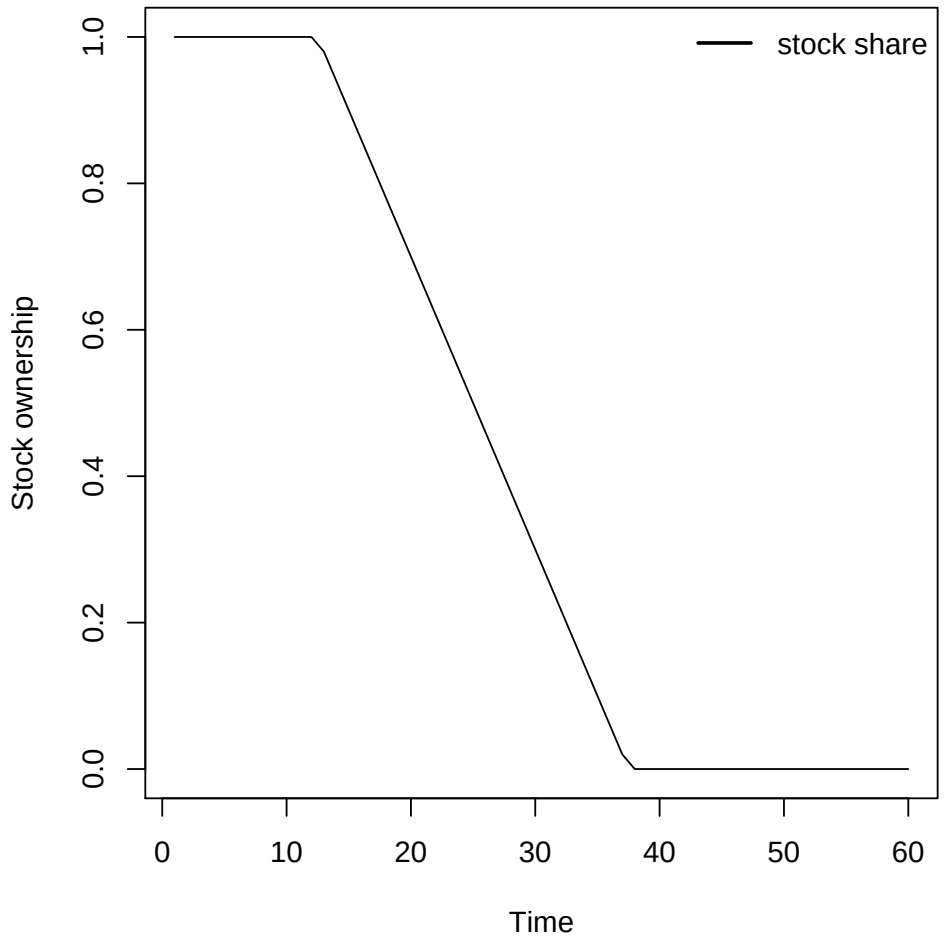
- The stock ownership ($\theta_{i,t}$) depends on sea surface water temperature (SST), and we assume SST is a positive deterministic trend of time t.

$$\theta_{1,t} = \begin{cases} 1 & t \leq t_0, \\ 1 - \alpha(t - t_0) & t > t_0, \end{cases} \tag{1}$$

where α–speed of transition, t_0–initial stock splitting year.

Spatial distribution shift

- The stock may be found entirely in the EEZ of country 1 or country 2, or split among the two, depending on SST.
- Countries negotiate on fixed catch share (FCS) that is fixed when agreement is binding.



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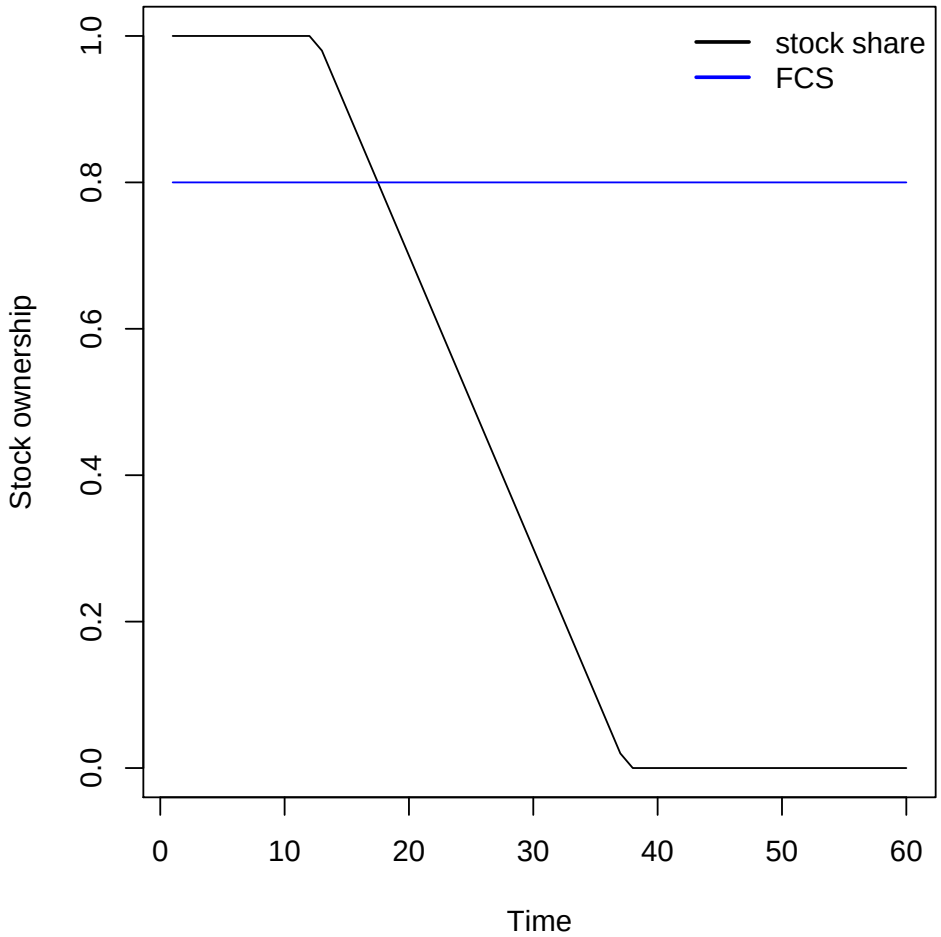

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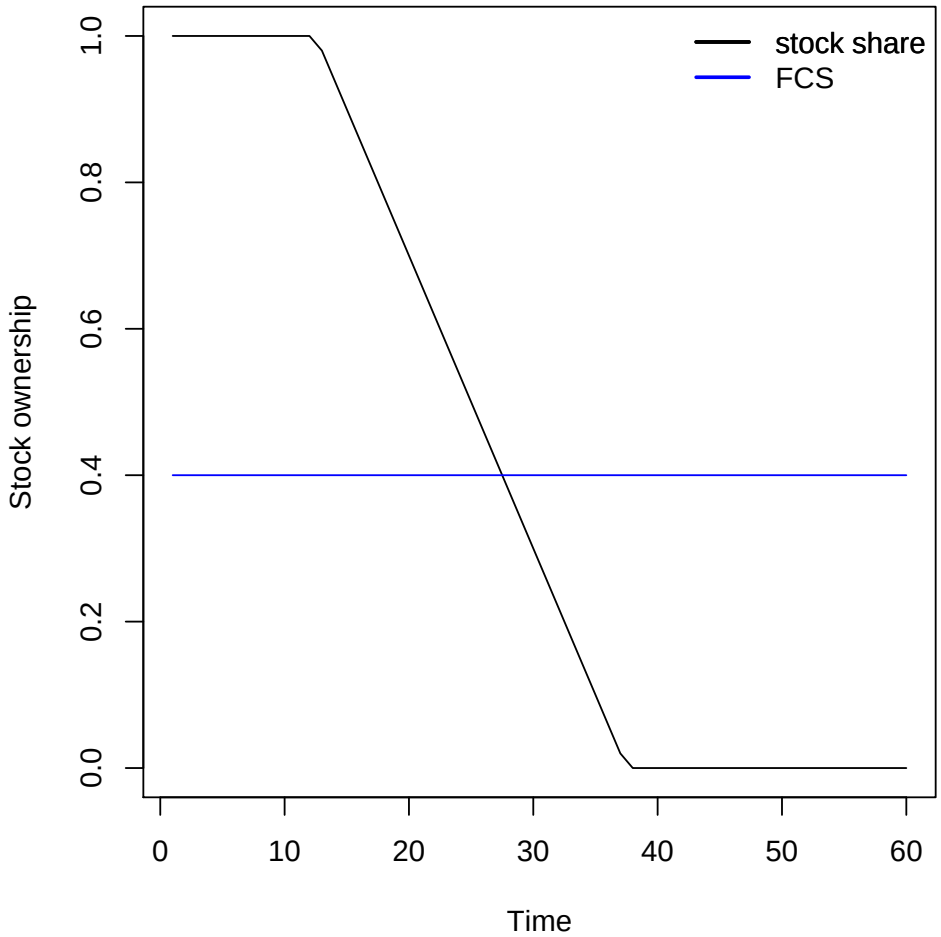


Model

Biological model

$$R_t(N_t) = aN_t(1 - N_t) + N_t + \varepsilon, \tag{2}$$

$$N_{t+1} = p_t R_t(N_t),$$

$$\frac{dC}{dt} = qE\rho, \rho = \frac{N^b}{\theta} \tag{3}$$

where **R**-recruitment, **N**- normalized stock abundance, **a**-growth parameter, **p**-escapement proportion; **C**- catch, ρ- stock density, **b**-schooling parameter, θ-stock ownership.

- Discrete time logistic growth;
- Stochastic recruitment (ε follows a beta distribution)
- Define instantaneous catch rate in terms of stock density (ρ) rather than abundance (N); e.g., $b = 0.75$.

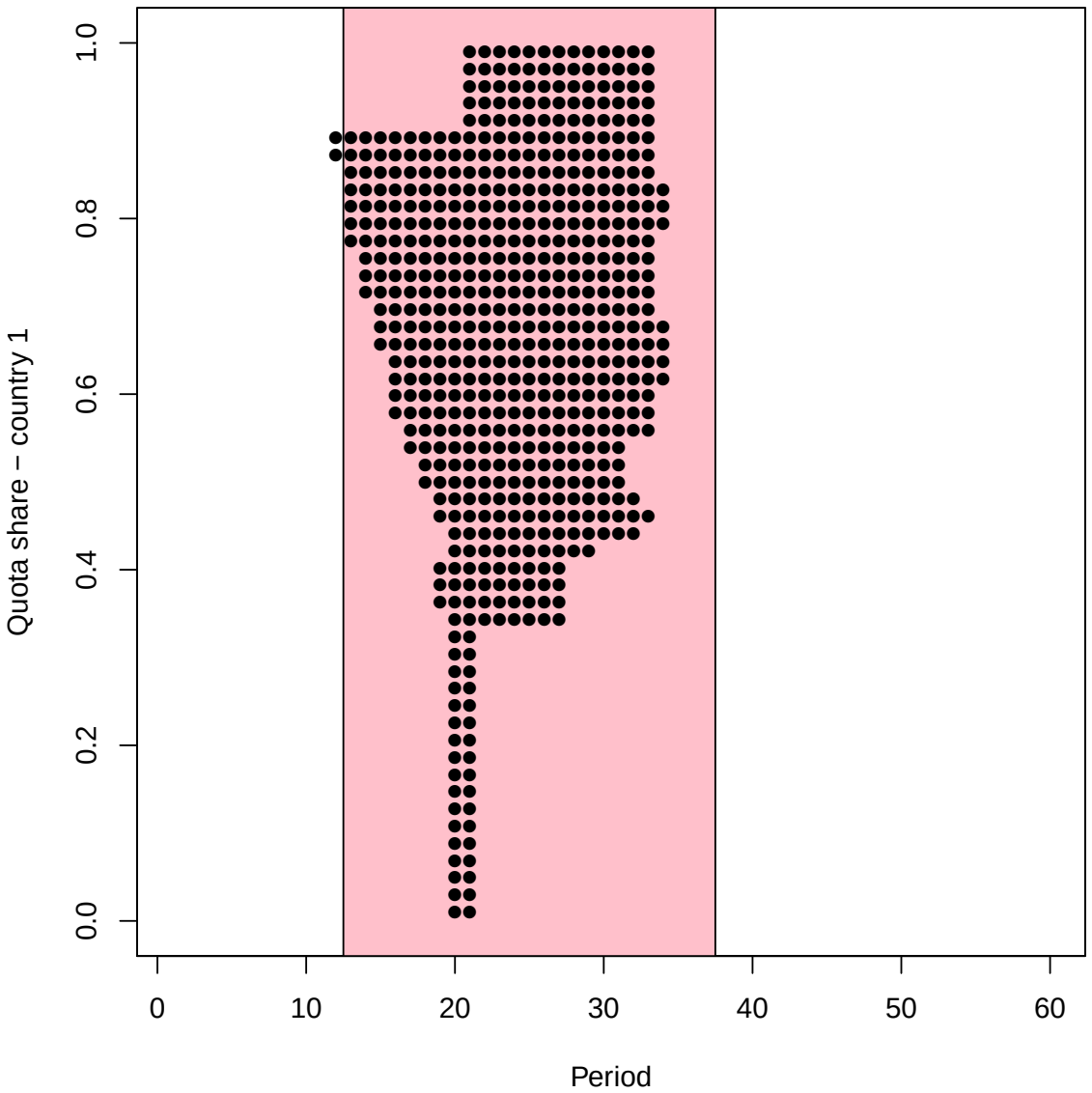
Economic model

$$V_t^i(R_t) = \max_{\mathbf{p}_t^i, G_t^i} \left\{ \overbrace{v_t^i(p_t^i, R_t, G_t)}^{\text{Current payoff}} + \overbrace{\sum_{k=t+1}^{t_{max}} \frac{v_k^i(p_k^i \mid p_k^{-i*}, R_k, G_k)}{(1+\gamma)^{k-t}}}^{\text{Discounted future payoff}} \right\}, \ i = 1, 2, \tag{4}$$

where **p**–escapement (proportion of stock left behind); ***G***–game strategy(cooperative, non-coop); **R**–stock size; γ–discount rate.

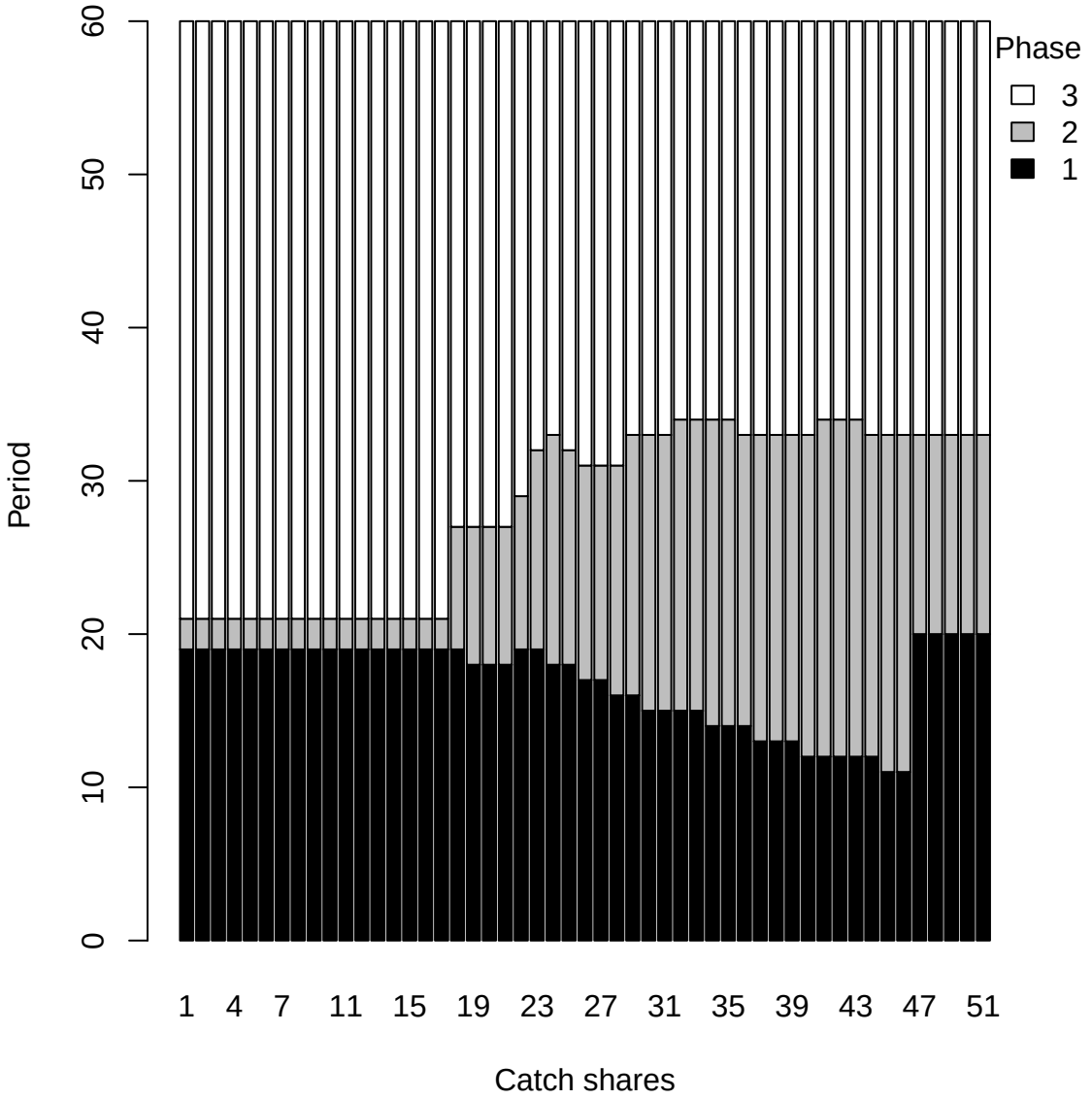
- Countries are profit maximizers; if playing non-cooperative strategy, they maximize their own net present values (NPV), joint NPV if playing cooperative strategy.
- The optimal harvest policies are closed-loop Nash equilibrium and satisfy two players' simultaneous Bellman equations.
- Dynamic programming, consisting of backward iteration and forward iteration.

Results: Game strategy



- Both countries have incentive to cooperate at least for some periods.
- Long cooperation can be achieved if country 1 is offered high FCS.
- Full cooperation is not possible.
- Asymmetric bargaining power.
- Instead of an "wait and see" strategy, the countries should enter the agreement relatively early during the transition.

Results: Game strategy



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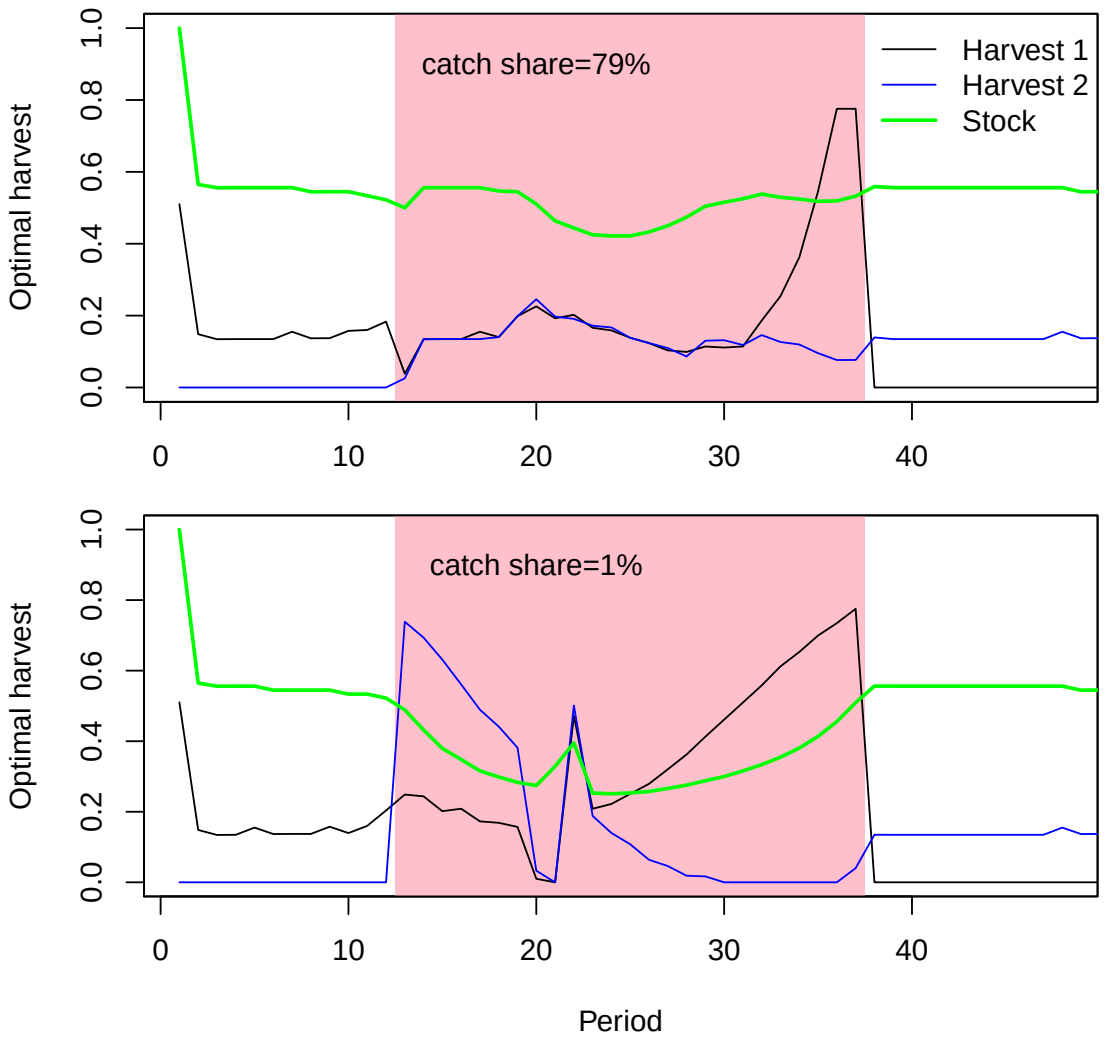
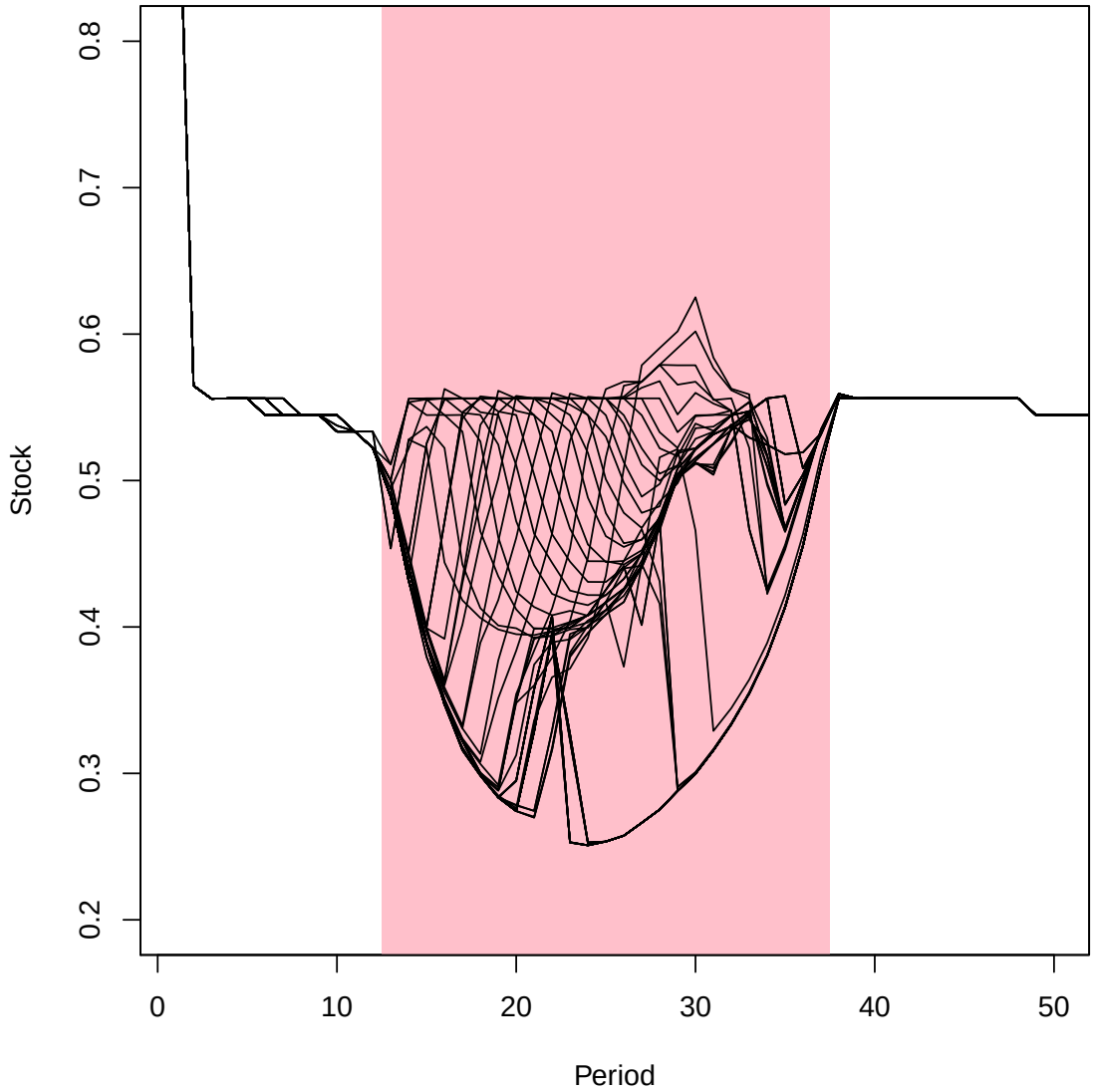
Results: Harvest trajectories under low and high FCS



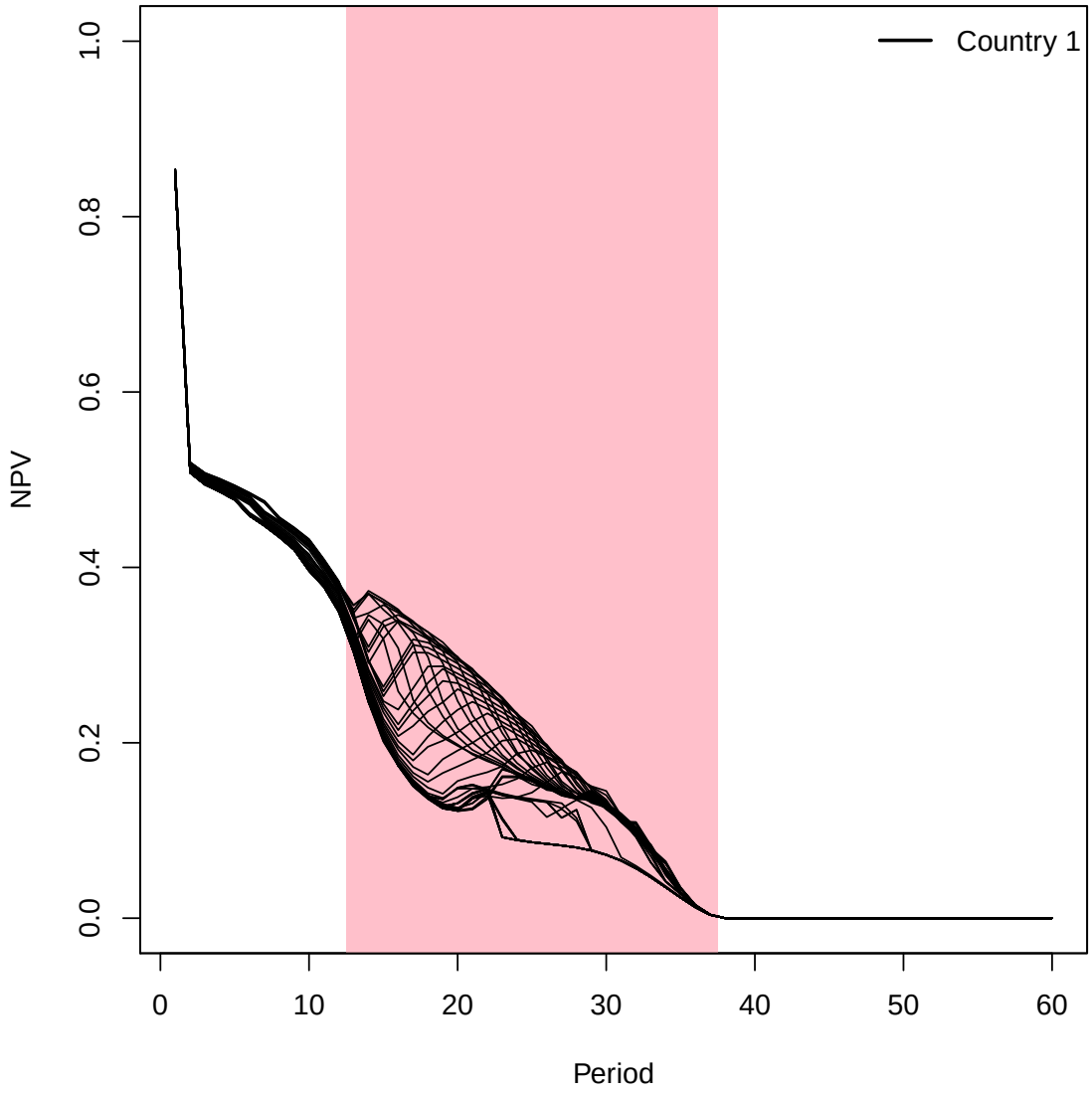
- When not in an agreement, the minor stock owner always harvests more aggressively than the major one, and stock is exploited to a lower level.
- Cooperation restricts the over-exploitation of the minor owner.
- Players in cooperation adopt a common but non-constant harvest strategies due to expectation.

Results: Stock

- Sometimes, it is optimal for stock to go above the single-owner optimum.



Results: Net present value



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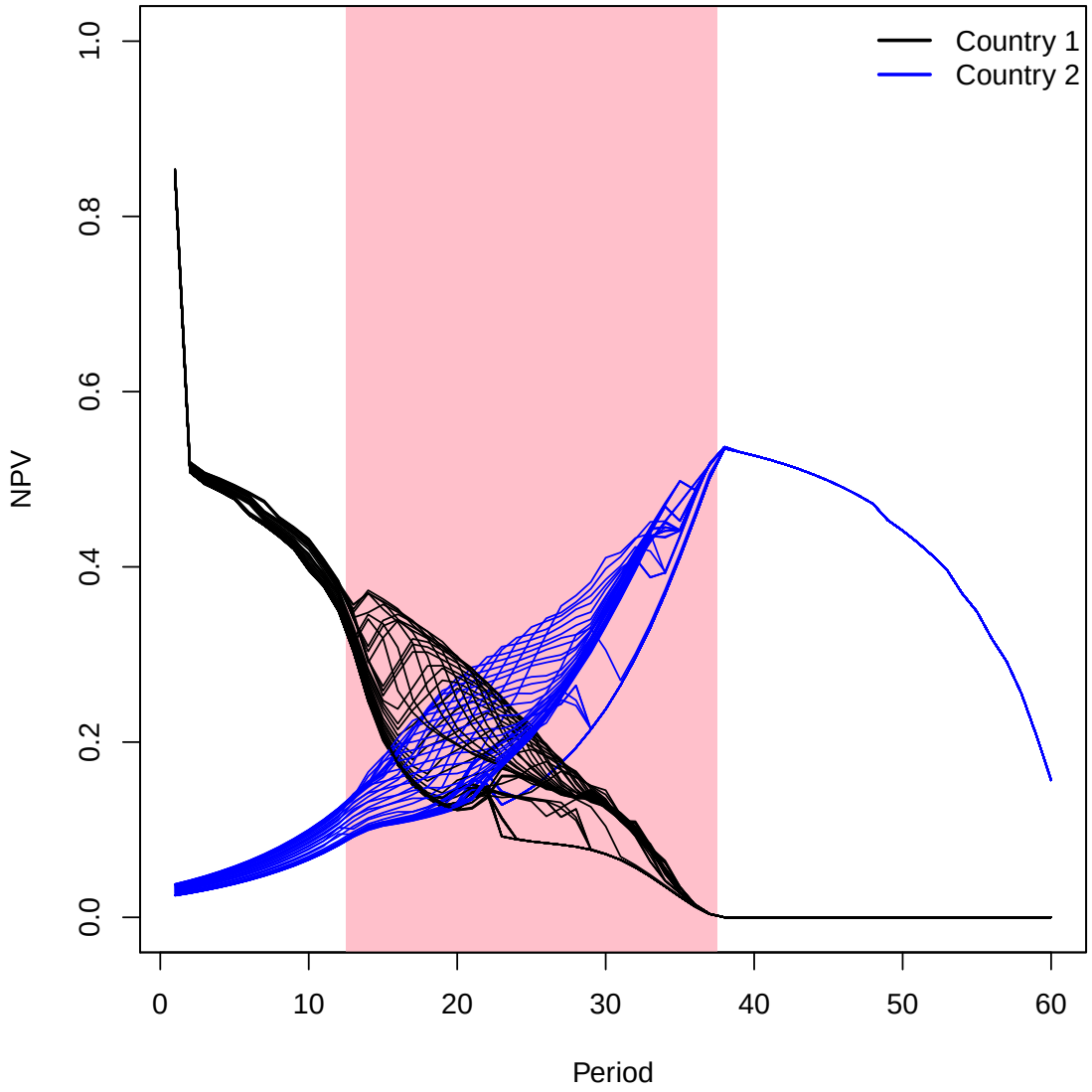

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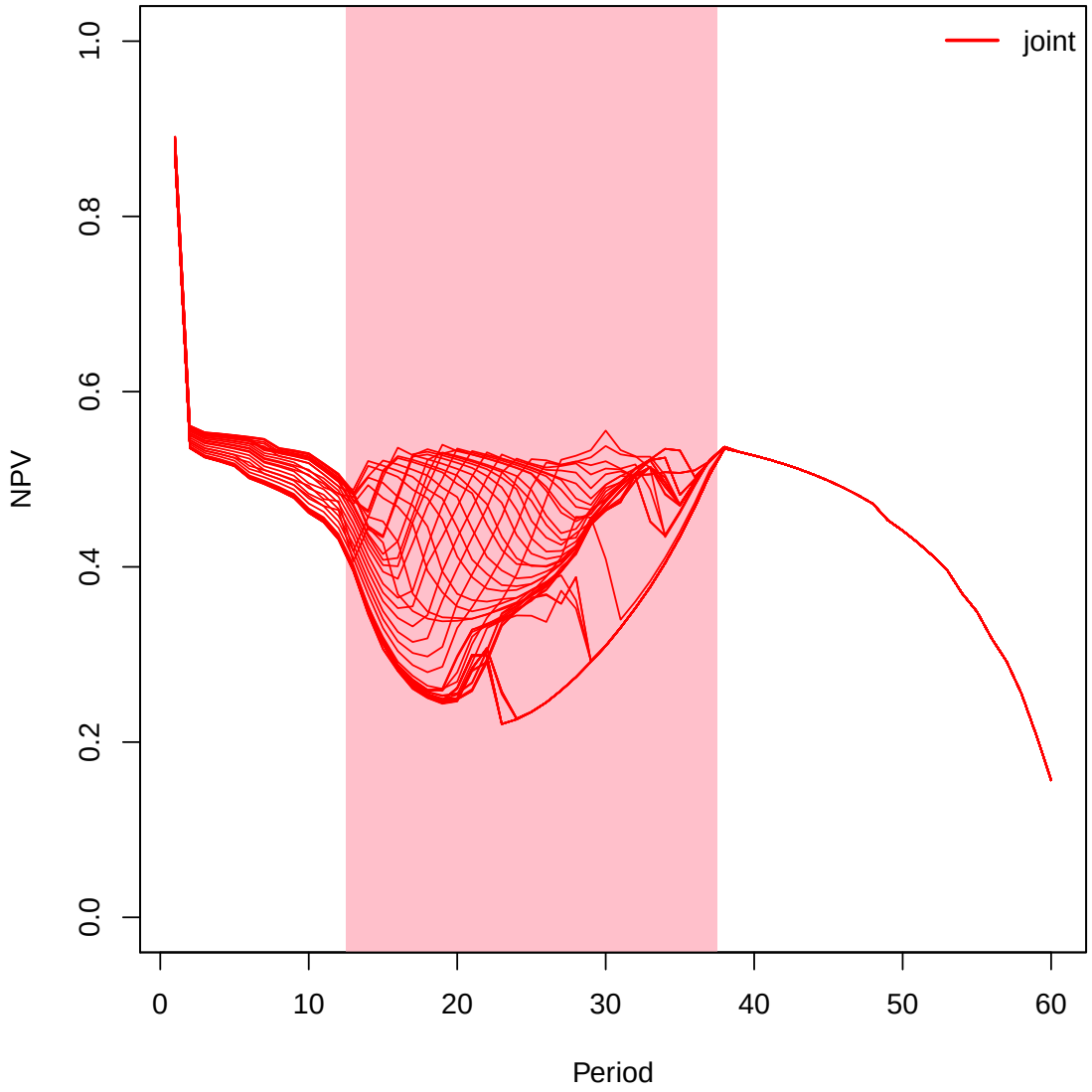
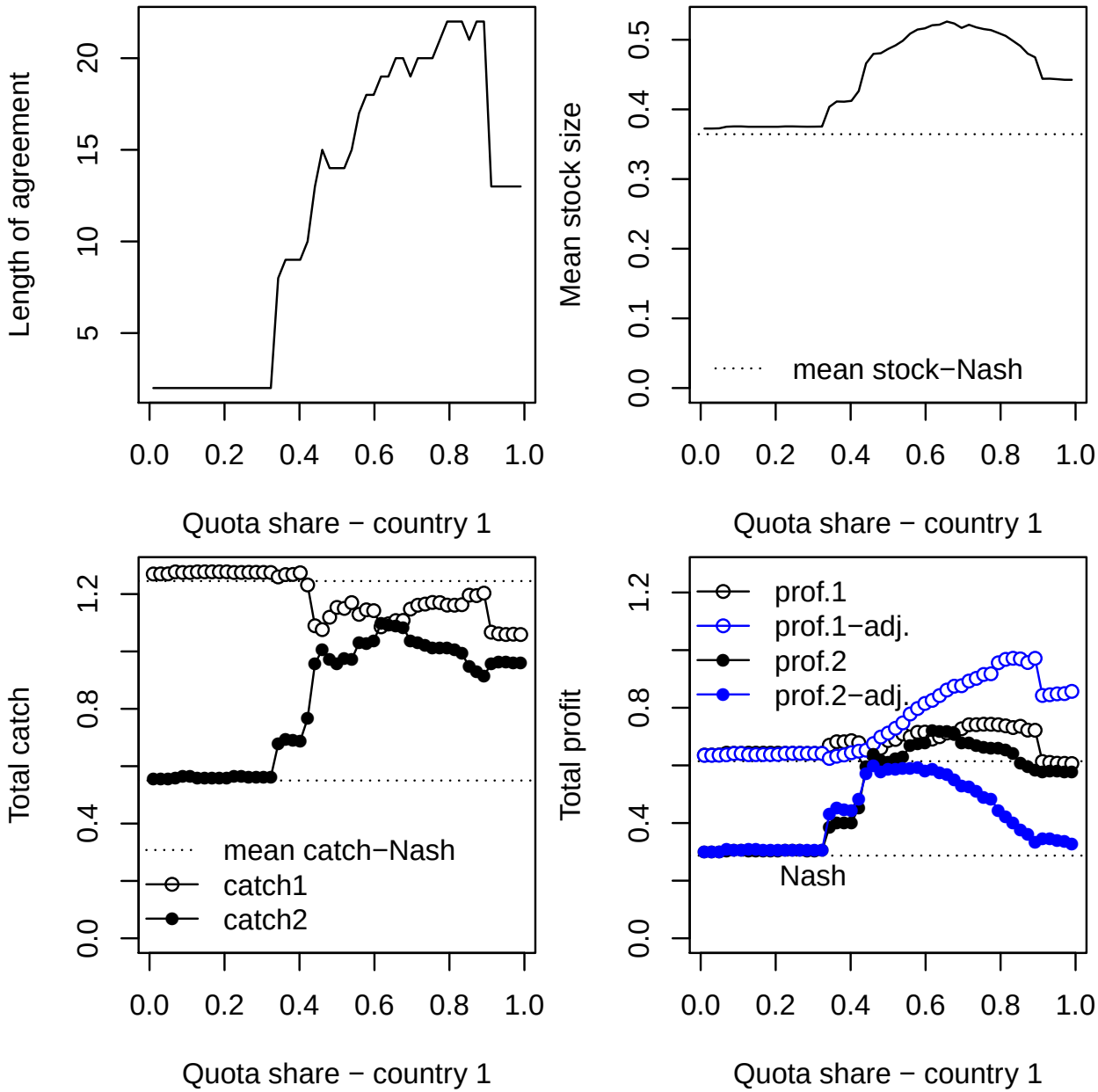


Discussion: policy selection criteria

The specific choice of FCS depends on the goal of fisheries management:

- If the goal were to maximize the duration of cooperation, then the stock losing country can demand fairly high FCS, up to 80% of the total catch that maximizes the joint NPV.
- If the goal were to maximize the mean transition stock, an optimal FCS can be found around an intermediate level (e.g., 60%).
- This intermediate level of FCS can also minimize the difference in total catch during the transition and require a moderate level of benefit transfer between the countries.

Discussion: policy selection criteria



Conclusion

- Transboundary fisheries agreement is hard to reach, and existing practices emphasize on relative stability of catch/quota shares.
- Under fixed catch share (FCS) scheme, it is possible to achieve long cooperation, but the stock losing country has much higher bargaining power, thus has to be offered higher FCS (e.g.,80%) relative to the stock receiving country.
- The window for cooperation lies on the early phase of stock transition, the "wait and see" strategy is not optimal and the countries should enter the agreement relatively early during the stock transition.
- When other criteria are concerned (transition stock, total catch difference and total side-payment), a more balanced catch share allocation (FCS of 60% for stock losing country) is more optimal.