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▶ To cite this version:

Jules Selles, Sylvain Bonhommeau, Patrice Guillotreau, Thomas Vallée. Influence of Tipping Points in the Success of International Fisheries Management: An Experimental Approach . 2018. hal-01719101

HAL Id: hal-01719101 https://hal.science/hal-01719101

Preprint submitted on 27 Feb 2018

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Influence of Tipping Points in the Success of International Fisheries Management: An Experimental Approach

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12

13 **Abstract** —International fisheries are common pool resources which concentrate management difficulties. 14 The migratory nature of fish resources makes it available for a large number of actual and potential harvesters 15 in high seas which are by nature, free of access. This work investigates the role of critical socio-economic 16 tipping points on cooperation during the policy-making process associated with international shared fisheries. 17 We analyze the ability of decision makers to coordinate their decisions to reduce economic rent dissipation 18 and to ensure resource sustainability in a dynamic environment. More specifically, we propose a 19 contextualized computer-based experimental approach to explore how decision makers respond to an 20 endogenously driven catastrophic change in the economic conditions. We use the study case of the East 21 Atlantic bluefin tuna (EABFT) fishery as it has been the archetype of an overfished and mismanaged fishery. 22 We show that the threat of a regime shift, by increasing the likelihood of an economic bankruptcy, fosters 23 more cooperative outcomes and a more precautionary management of the resource. This result is exacerbated 24 when the position of the tipping point which triggers the shift in economic condition is uncertain.

25

Keywords— Experimental economics; Fisheries management; Common pool resources, Tipping points;
 International fisheries; Policy making.

29 **1. Introduction**

30 Fishery resources are common-pool resources (CPRs), in which appropriation (catch) of the 31 resource by one fisher creates an external cost for others. In such a context, the incentives to 32 catch more resources and ignore the external costs are rational because a fisher receives 33 benefits for himself without bearing the social costs. Collectively, this rational individual 34 behavior leads to the well-known tragedy of the commons (Gordon 1954; Hardin 1968). 35 Fisheries management has faced difficulties all over the world for the second half of the 20th 36 century and the beginning of this century to address both conservation and economic challenges 37 (Pauly et al., 1998; Worm et al., 2009). Scientists have pointed out the poor governance practices 38 and deficient incentives for conservation (Hilborn et al., 2005).

39 International fisheries in the high seas are a special case which causes particular management 40 problems. International shared fish stocks are defined as fish stocks not confined to a single national jurisdiction (Economic Exclusive Zone, EEZ), and exploited by more than one State 41 42 (Munro, 2004). Compared to domestic fisheries, international fisheries are subject to 43 management difficulties mainly due to the need for cooperation between different countries 44 (Munro 1979, Munro et al., 2004, Maguire et al., 2006, McWhinnie 2009, Teh & Sumaila, 2015). 45 Inadequate management has led to overfishing of many economically important fish stocks 46 (Cullis-Suzuki & Pauly, 2010). Highly migratory fish stocks represent the most complex case of 47 international fisheries. The highly migratory nature of such fish resources makes it available for 48 a large number of actual and potential harvesters in high seas which are by nature free of access 49 (White & Costello 2014). Nowadays, the current status of a number of highly migratory stocks 50 (mainly tuna and tuna-like species) is particularly worrying (Juan-Jorda et al., 2011). Since the 51 1995 United Nations Fish Stocks Agreement, highly migratory species have been managed on a 52 regional basis through Regional Fisheries Management Organizations (RFMOs). The RFMOs are 53 composed of members from both coastal states and distant water fishing nations (DWFNs). 54 Despite the legal obligation to cooperate within a RFMO, the states involved in international 55 fisheries are not required to reach an agreement, or if an agreement is achieved, it is not binding 56 or enforceable (Munro et al., 2004). This means that non-cooperation is the default option, 57 notably in front of the complexity to manage highly migratory species and reach stable 58 agreements.

An example is given by the East Atlantic and Mediterranean stock of bluefin tuna (EABFT), a highly migratory species. Until 2009, the stock has been deemed an archetype of overexploitation and mismanagement (Fromentin et al., 2014). Several countries, both coastal and DWFNs, have contributed to a high level of exploitation driven by the high market value of the tuna on the Japanese market (Fromentin et al., 2014). The decline in the EABFT stock has

raised considerable concerns about its management (ICCAT, 2007, Hurry et al., 2008, ICCAT, 64 2009). Under the governance of the International Commission for the Conservation of Atlantic 65 66 Tunas (ICCAT), the fishery has suffered both from its failure to follow the scientific advice and a high level of illegal, unreported and unregulated (IUU) fishing. This situation has occurred since 67 the establishment of the first management regulation based on quotas (Total Allowable Catch, or 68 69 TAC) in 1999 and lasted until 2009. At this period of time, the objective to reach the Maximum 70 Sustainable Yield (MSY) was far from being achieved. It is only under the threat by 71 environmental Non-Governmental Organizations (NGOs) to propose listing EABFT in Appendix I 72 of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) 73 which would have prohibited any international trade for this species, that ICCAT established a 74 recovery plan for EABFT since 2009. For the very first time, ICCAT has fully endorsed scientific 75 advice and reached an agreement to considerably reduce the fishing effort and allowable catch 76 as well as implementing some management measures (e.g., size limitations, fishing seasons).

Game theory offers important results about the outcomes of non-cooperative harvest (since the
seminal work of Munro 1979, Levhari & Mirman, 1980 and Clark 1980) and the benefits to reach
and maintain cooperative agreement in the context of international fisheries (e.g., Brasao et al.,
2000, Pintassilgo et al., 2003, 2010, 2015; for a review see Bailey et al., 2010, Hannesson 2011,
and Sumaila 2013). However most of the game theory applications in fisheries exclude complex
resource dynamics or potential changes in the management framework (Bailey et al., 2010).

83 As observed in the case of the EABFT fishery, society and public opinion put pressure on RFMOs 84 to address urgently such complex problems, particularly if they perceive a risk of critical 85 threshold to be exceeded. Beyond a critical threshold, management systems can switch swiftly to a high action level with new management frameworks and paradigms (Scheffer et al., 2003). 86 87 This is the parallel of regime shifts in ecology which are large, abrupt and persistent changes in 88 the structure and function of an ecosystem (Biggs et al., 2012). The point where the shift occurs 89 is called a tipping point. The effects of such tipping points could play an important role in the 90 management of common resources in a high hierarchical and centralized institution, such as the 91 ICCAT or the European Union (EU). The political management systems propose very few 92 incentives to achieve the long term sustainability of stocks (Daw & Gray, 2005). Moreover, 93 stakeholders impacted by ecosystem management may prefer some stability and avoid 94 continuous and costly changes in management recommendations (Armsworth & Roughgarden 95 2003, Patterson & Resimont 2007, Boettiger et al., 2016). Drastic adjustments to reach stocks 96 sustainability are often taken only once the state of the resources has called society attention 97 (e.g EABFT fishery case in Fromentin et al., 2014).

- An empirical method to explore conditions of cooperation in a complex socio-economic system,
 such as international fisheries, relies on laboratory experiments. Experimental studies on CPRs
 - 3

100 have proven to test effectively the impact of specific variables in repeated controlled settings 101 (Ostrom 2006). Our objective is to analyze the ability of decision makers to coordinate their 102 decisions in order to reduce economic rent dissipation and to ensure resource sustainability in a 103 dynamic environment. In the present research work, we assess the cooperation in response to 104 the introduction of endogenous socio-economic tipping points with or without uncertainties. 105 The socio-economic shift considered in this study is a latent and endogenous cost driven by 106 collective actions (aggregated catches). We design our experiment to the case study of the 107 EABFT exploitation following Brasao et al., (2000). Subjects, who are representatives of identical 108 States, are involved in the EABFT fishery management by defining their own catch level 109 (quotas). Our approach can be applied to a variety of CPR situations and collective action 110 problems (Ostrom, 2006, Poteete et al., 2010, Anderies et al., 2011), but our focus in this paper is 111 on ensuring sustainable exploitation of fish stocks...

Using a dynamic CPR game framework, Lindahl et al., (2016) already studied how the 112 113 introduction of an ecological tipping point affects the productivity of the resource affects, hence 114 the profitability of CPR users. They showed that a group of users manages a resource more 115 efficiently when confronted to a latent abrupt change. Schill et al., (2015) extended these results 116 by showing that the threshold impact on resource utilization is observed only in situations 117 where the likelihood of the latent shift is highly probable. We extend the experimental work of 118 Lindahl et al., (2016) by testing the effect of the inclusion of a tipping point affecting the 119 economic conditions of the dynamic game in which subjects decisions are based on economic 120 outcomes. We also extend the work of Schill et al., (2015) by analyzing how the position of a 121 latent shift affects resource management instead of analyzing the effects of the occurrence 122 probability.

123 2. Experimental setting

124 **2.1. Experimental design**

125 Research questions are tested using a modified version of the experimental design of Mason & 126 Philips (1997). This protocol defines a CPR request game (Budescu et al., 1995), in which a few 127 firms harvest a resource in a dynamic context. We adapt their oligopoly model to a situation 128 where the price is exogenously determined (constant price) and include a critical tipping point 129 in the resource level which affects the economic conditions of the game. Following the 130 methodology used in other complex ecological dynamic experiments (Schill et al., 2015, Lindahl 131 et al., 2016), we introduce a non-neutral framework. The task and information given to subjects 132 correspond to a stylized representation of the actual context of the ICCAT decision committee. 133 The subjects are asked to define their harvest levels (quotas) for the East stock of Atlantic Bluefin tuna, instead of collecting tokens (Harrison and List 2004 for a characterization of experiments). Subjects are only able to communicate through a non-binding pledge process: face to face communication is not allowed. Moreover, to approximate an infinite time horizon supergame, the subjects do not know the number of rounds to be played¹; they only know the maximum duration. However, we make sure to end the experiment early enough to avoid

139 potential end game effects.

140 We align our experiment onto the model of Hannesson (1997). The yearly CPR biomass 141 dynamics (B_t) is modeled by a logistic growth (1) subject to fishing (Y_t).

142
$$B_{t+1} = G(B_t) - Y_t$$
 (1)

143 With *t* theyear and $G(B_t) = round \left(B_t \cdot \left[1 + r \cdot \left(1 - \frac{B_t}{K}\right)\right]\right)$.

We assume that the marginal cost of fishing (*c*) is inversely proportional to the size of the stock
at any point in time². The total cost (C) in period t will then be:

146
$$C(B_t) = \int_{B_t}^{G(B_{t-1})} \frac{c}{x} dx = c. \left[\ln(G(B_{t-1})) - \ln(B_t) \right]$$
(2)

147 The fish harvest Y_t caught in period t could be described by $G(B_{t-1}) - B_t$. At a given constant 148 price (*p*), the total profit (π_t) obtained by all players (*i*) in period t with a fixed cost (α) 149 associated with an endogenous resource threshold B_{lim} . will be:

150 $\begin{cases} \pi_t = p. Y_t - C(B_t), & \text{for } B_t \ge B_{lim} \\ \pi_t = p. Y_t - C(B_t) - \alpha. N, & \text{for } B_t < B_{lim} \end{cases}$ (3)

151 With N the number of participants, and assuming constant return to scale, the individual profit is

152
$$\pi_{i,t} = p.y_{i,t} - C(B_t).\frac{y_{i,t}}{Y_t}$$
, for $B_t > B_{lim}$ and $\pi_{i,t} = p.y_{i,t} - C(B_t).\frac{y_{i,t}}{Y_t} - \alpha$, for $B_t \le B_{lim}$.

We introduce a fixed cost related to the resource size beyond the threshold level. This cost is a stylized representation of the critical effect of resource depletion. In the case of the EABFT fishery, this cost represents the effect of a ban on the species commercial exchange. This fixed cost formulation follows the assumptions from public good games with potential catastrophic effects of climate shifts (Milinski et al., 2008, Barret & Danenberg 2012, 2013).

We introduce the resource growth model as a discrete function to our subjects (Figure 1) and the associated profit evolution as depending on the stock and catch levels (Figure 2) for a selection of parameters that fit the context of EABFT (stylized version, Table 1). The minimum resource size allowing for reproduction is 3 units (1 unit is equivalent to 10^4 tons) and the maximum resource size is set to 70 units. The maximum sustainable yield (MSY) is 3 units for a stock size between 28 to 42 units. The profit is maximum, greater than 100 units (1 monetary unit is equivalent to $10^7 \in$), when both the stock and catch levels are maximum, then it steadily

¹As in Lindahl et al., (2016), to ensure an unknown time horizon, we varied the end-time between and within groups.

² This cost function implicitly assumes that the cost per unit of fishing effort is constant and the catch per unit of effort is proportional to the size of the exploited stock.

- decreases until the stock reaches the lowest values and becomes null at any catch level for a stock size of 10 units. In all treatments, the groups start with a stock size of 52 units and over a number of periods unknown to them, they harvest resource units restricted by an individual capacity constraint of 5 units ($y_{i,t}$ =[0,1,2,3,4,5]). Groups are composed of 3 subjects sharing the same characteristics. This design follows the stylized representation from a game theory model
- 170 of the EABFT fishery (Brasao et al., 2000).
- 171
- 172 **Figure 1:** Profit ($10^7 \in$) as a function of stock (10^4 tons) and harvest level (10^4 tons).



173

174 **<u>Figure 2:</u>** Logistic resource growth (10^4 tons).



177 **<u>Table 1:</u>** Bioeconomic model parameters.

Variable	Description	Value
N	Participant number	3
y max	Maximum harvest [10 ⁴ t]	5
р	Price [10 ⁷ €/10 ⁴ t]	10
r	Growth rate	0.15
К	Carrying capacity [10 ⁴ t]	70
с	Cost parameter [10 ⁷ €/104t]	100
α	Threshold fixed cost [10 ⁷ \$]	30
B_{lim}	Threshold [10 ⁴ t]	20

178

179 We introduce three experimental treatments to assess the cooperation in response to the 180 introduction of three kinds of endogenous socio-economic tipping points: i) base case without 181 tipping point; ii) known tipping point and iii) uncertain (localized) tipping point. In all three 182 experimental treatments (T0, T1 and T2 in Table 2), a group of subjects defines a catch harvest 183 for their own EABFT fishery. The only aspects that differ between treatments are the nature of 184 the threshold (B_{lim}) . The uncertainty surrounding the latent endogenous shift differs from the 185 risk evaluated by Schill et al., (2015). In our case, the uncertainty focuses on the position of the 186 threshold, and not on its existence. The third treatment (T2) introduces uncertainty around the position of the threshold value B_{lim} which is drawn within a 40% uncertainty range $[B_{lim}^{min}, B_{lim}^{max}]$ 187 188 centered around the value of B_{lim_3} .

189

	Treatment 0	Treatment 1	Treatment 2
Nature of threshold	No Threhold	B _{lim}	$[B_{lim}^{min}, B_{lim}^{max}]$
Description	Baseline treatment	Subjects both know that there is a threshold and its position.	Subjects know that there is a threshold but they do not know its position, only a range with equal possibility.
Number of groups	6	6	5
Number of subjects	18	18	15
Number of group observation	2	2	2
Number of experiments	12	12	10

190 **<u>Table 2:</u>** Experimental design.

191 **2.2. Experimental procedure**

192	The experiment was conducted at the experimental laboratory of the University of Montpellier
193	(LEEM) with a total of 51 subjects drawn from the undergraduate student population in May
194	2017. The experiment was conducted through a computer-based approach realized with the
195	oTree software (Chen et al., 2016). Each experimental session lasted a maximum of two hours

³ A 40% was selected to represent a high uncertainty level around the position of B_{lim} .

with two repetitions of the game for the same group of subjects (phases). Participants received a
show-up fee of 6 € and the average earnings during the experiments were 2.94 €, paid privately
at the end of the experiment.

199 When the subjects arrived, they signed a consent form and were randomly assigned to a group of 200 3 subjects with the instructions to read (Appendix A). They were told that each subject 201 represented a country, and that, together with the two other participants of their group, they 202 had access to the stock of the East Atlantic bluefin tuna, a common renewable resource, from 203 which they had to decide the amount of allowable harvest for their fishery at the beginning of 204 each round (each year), before deciding privately in a further step what would be their own 205 harvest decision. Subjects were told that the experiment would end either when the stock is 206 depleted or when the experimenter decides to stop it, but the exact end-period was unknown to 207 them. They began with a capital of 50 monetary units and were paid proportionally to their 208 accumulated profit during the experiment with a rate of 1 unit equal to $0.05 \in$ plus an additional 209 revenue of 0.2€ for correct belief elicitation. Belief elicitation constitutes a guess of the 210 expectation of other subjects' behaviour (harvest level). They received payment for only one 211 phase of the experiment randomly chosen and unknown to them. No direct communication (face 212 to face) between subjects was allowed.

213 Before the start of the experiment, the subjects were asked to fill out a form to inform their 214 identity and if they were concerned or involved with the subject of the study (Appendix B), and 215 then they were tested for their understanding of the instructions, i.e. resource dynamics and 216 profits (3 questions, Appendix B). Any remaining question was answered by the experimenter. 217 For each round, players received information about the resource state from which a profit table 218 is derived and updated for every round (Appendix C). They were also informed about the 219 percentage variation of the biomass for the next year through a variation table depending on the 220 harvest level of the group (Appendix C). Furthermore, the mean resource level at MSY (35 units) 221 was also indicated with the resource status and defined as a non-binding objective for the group. 222 This information creates a collective reference point in order to facilitate the understanding of 223 the long term sustainable resource level maximizing the growth of the resource. Therefore, 224 optimizing the use of the resource can focus on the mere level ensuring maximum profits. This 225 information is necessary to concentrate the problem on the resource sharing issue, and not on 226 the optimization of a non-linear dynamic system which proved to be a complex problem 227 (Moxnes, 1998 and Hey et al., 2009).

On top of deciding their harvest level, the subjects had to guess the sum of harvest units they
expected the other players would harvest in each period from 0 to 10 units. Belief elicitation was
incentivized with a payoff of 0.2 € for good prediction and allowed examining the source of

- 231 deviations from theoretical predictions. Thereafter, participants pledged an amount of catch
 - 8

232 they would harvest individually. It was common knowledge that these declarations were non-233 binding but would be communicated to the group. After these declarations were revealed, the 234 participants chose simultaneously their actual harvest level for the round (year). At the end of 235 the round, the participants were then informed about everyone's decisions for the round and 236 they were given their cumulated profit and the track records of the total catch, profit and own 237 decision during the game. They also had access to a projection of the future resource status 238 assuming a constant harvest level scenario defined at the current harvest level (Appendix D). At 239 the end of the experiment, participants were informed about their cumulated profit. They were 240 also asked to indicate, on a five-point Likert scale, to what extent they understood the resource 241 dynamics and the cooperation level of their group during the experiment.

242 **2.3. Formulating hypothesis**

To formulate the research hypotheses, we rely on the analysis of an indefinite time horizon supergame made by Hannesson (1997). The subjects know that the game will end at some point but not when. At every round of the game, each subject *i* in the group has an individual perception about whether or not the game would last another round (sort of a discount factor), which we denote δ_i (Fudenberg and Tirole 1998). The implication of these subjective probabilities defines the equilibrium conditions of the game.

During the experiment, participants receive updates on the stock level B_t and on their available profit at the beginning of each period. They also know if someone deviates from its proposition and if a participant behaves as a selfish agent. Thereby, each participant conditions his strategy on past and current resource and profit levels. On the basis of this information, each participant plays a Markov strategy (Maskin and Tirole 2001). Because players are symmetric (same cost functions), we only consider equal sharing equilibria (equal share of the resource) in which each subject gets $\frac{1}{N}$ of the total profits of each period.

Cooperative strategy could be sustained by a trigger strategy in the game. Considering the case without tipping point, if one of the participants deviates from the optimal solution, she/he would gain more in the current period and would then be punished afterwards. Other players would retaliate by fishing down the stock in the following periods until further depletion becomes unprofitable. Such a scenario results in resource depletion until the marginal cost of fish caught (*c*) is equal to the marginal revenue, i.e. the fish price (*p*, Eq. 3). The size of the stock resulting from such a strategy is then:

263

$$B_{tr} = \frac{c}{p} \qquad (4)$$

264 Otherwise, the optimal solution could be sustained as a Markov perfect strategy if the defection 265 is not profitable. The net present value of the cooperative strategy, NPV_c , for infinite horizon is:

266
$$NPV_{c} = \frac{\pi_{0}}{N} + \frac{\pi_{c}}{N} \cdot \frac{\delta}{1-\delta}$$
(5)

With an initial stock of 52 units (10⁴ tons), the optimal outcome is obtained by harvesting the stock until the optimal level, B_{opt} is reached in the first period, each subject gaining $\frac{\pi_0}{N}$. In each subsequent period, the group harvests the sustainable yields [$G(B_t)$] until the stock reaches its optimal size B_{opt} and each subject obtains $\frac{\pi_c}{N}$.

The net present value (NPV_d) of the non-cooperative strategy is defined for a participant who deviates from the cooperative solution and which is then punished by all other participants playing non-cooperatively afterwards and forever⁴.

274
$$NPV_{dev} = \frac{\pi_0}{N} + \frac{\pi_c}{N} \cdot \delta + \pi_d \cdot \delta + \frac{\pi_p}{N} \cdot \delta^2 + \frac{\pi_{tr}}{N} \cdot \frac{\delta^3}{1-\delta}$$
(6)

275 With
$$\pi_{opt} = p.(G(B_{opt}) - B_{opt}) - c.[ln(G(B_{opt})) - ln(B_{opt})];$$

276
$$\pi_d = p.(B_{opt} - (B_d)) - c.[ln(B_{opt}) - ln(B_d)];$$

277 $\pi_p = p.(G(B_d) - B_{tr}) - c.[ln(G(B_d)) - ln(B_{tr})]$ and

278
$$\pi_{tr} = p.(G(B_{tr}) - B_{tr}) - c.[ln(G(B_{tr})) - ln(B_{tr})]$$

279

In the first two periods, the defector gets the same profit as in the cooperative solution, as all other participants play cooperatively, and in addition the defector gets the profit of driving the stock down unilaterally to B_d (and get π_d). In the third and all later periods, he will be punished by all other agents playing non-cooperatively, driving the stock down to the level B_{tr} . (10 units) and gets the profit $\frac{\pi_p}{N}$. Then, the defector gets only the profit obtained in the non-cooperative solution $\frac{\pi_{tr}}{N}$.

The trigger strategy forms a subgame perfect equilibrium, if the defection is not profitable, $NPV_c > NPV_d^5$, which gives the condition:

$$\pi_c > \frac{1-\delta}{\delta} \cdot N \cdot \pi_d + (1-\delta) \cdot \pi_p + \delta \cdot \pi_{tr}$$
(7)

$$NPV^{c}(B_{t}) > \pi^{d} \left(y^{d}(B_{t}) \right) + \delta . NPV^{d}(B_{t})$$

⁴ Punishment strategies may last a finite number of periods. As we are interested in the effects of increasing the fishing through the introduction of a tipping point we keep simple strategies.

⁵ A more general way to describe the conditions for cooperation can be defined following the logic of Mason & Phillips (1997). Consider a cooperative harvest function, $y^c(B_t)$, a trigger strategy can be described by playing cooperatively $y^c(B_t)$, as long as no one has defected. If one of the participants deviates from the optimal solution, then others will punish him by fishing down the stock with harvest $y^d(B_t)$, afterwards and forever. Using the cooperative harvest and resulting stock path, we may derive the net present value for the player under cooperation $NPV^c(B_t)$. Similarly, we may calculate the non-cooperative value function, $NPV^d(B_t)$. The trigger strategy forms a subgame perfect equilibrium if the defection is not profitable, irrespective of the current state.

289 As δ tends to 1 (i.e. the discount rate tends to 0), defection will never be profitable (by definition 290 $\pi_c > \pi_{tr}$). In other words, the loss from punishment will always outweigh the gains from 291 defecting. As δ becomes inferior to 1, the temporary gains from defecting may outweigh the long 292 term profit of playing cooperatively. Moreover, the temptation of defecting decreases with 293 higher fishing costs. A higher cost of fishing (*c*) increases the likelihood of a cooperative solution 294 (the demonstration can be found in Hanneson, 1997). However, the introduction of a fixed cost 295 triggered by fishing down the stock below the threshold B_{lim} changes the size of the stock resulting from non-cooperative strategy B_{tr} from a level where further depletion becomes 296 297 unprofitable (since the marginal cost of fish caught is equal to the price) to the level of the 298 threshold B_{lim} which is by definition superior to B_{tr} ($B_{tr}=c/p$). Consequently, the gains from the 299 cooperative solution relatively to the non-cooperative solution become smaller and for low 300 discount values the cooperative and non-cooperative solutions coalesce and lead to our first 301 hypothesis.

302

Hypothesis 1 We expect less cooperation when a tipping point is introduced⁶ (T1 and T2).

304

314

We analyze the level of cooperation through the stock size left after exploitation. A stock size below the optimal level (B_{opt}) indicates an over-exploitation drives by non-cooperative behaviours. We also introduce a proxy of non-cooperative behaviours, the ratio between the harvest decision $(y_{i,t})$ and the myopic harvest strategy $y^e(B)$.determined as a function of the stock size (see Appendix G for a description of the myopic harvest strategy $y^e(B)$). A value equal to 1 indicates that the participant chose to play as a selfish harvester maximizing his current payoff⁷, whereas a value inferior to 1 indicates that the participant intended to cooperate.

Now turn to the case where the position of the threshold is uncertain. Considering risk-neutralplayers, the problem facing by each subject is now:

$$\pi_{i,t} = \begin{cases} p. y_{i,t} - C(B_t).\frac{y_{i,t}}{Y_t}, \text{ for } B_t > B_{lim}^{max} \\ p. y_{i,t} - C(B_t).\frac{y_{i,t}}{Y_t} - \alpha. \left[1 - \left(\frac{B_t - B_{lim}^{min}}{B_{lim}^{max} - B_{lim}^{min}} \right) \right], \text{ for } B_t \in [B_{lim}^{min} B_{lim}^{max}] \\ p. y_{i,t} - C(B_t).\frac{y_{i,t}}{Y_t} - \alpha, \text{ for } B_t < B_{lim}^{min} \end{cases}$$
(8)

In face of ambiguous situation, the size of the stock resulting from non-cooperative strategy (where further depletion becomes unprofitable) becomes superior to B_{lim} when an uncertain

tipping point is introduced (T2). Following the same rationale as for defining hypothesis 1, the

⁶ For our parameterization we calculate in Appendix F, the relationship between the critical value of the discount rate (δ) and the number of participants (N) compatible with a self-enforcing cooperative solution (Equation 7).

⁷ Myopic behavior constitutes a focal point distinguishable as the symmetric harvest decision which maximizes the current payoff (diagonal in the payoff table in Appendix C).

gains from the cooperative solution relatively to the non-cooperative solution become smallerand lead to our second hypothesis.

320

Hypothesis 2 We expect less cooperation in T2 than in the known threshold position treatmentT1.

323 **2.4. Statistical Analysis**

We first compare means and proportions across the treatments of main variables (Table 3). We used respectively the non-parametric Kruskal-Wallis and a Pearson's chi square tests for comparisons of means and proportions (Table 4). All reported p-values are two-sided and we only consider the first 15 rounds of the game for our analysis.

328 Then, we analyze pledges and players' beliefs by classifying subjects according to their ability 329 during the experiment to predict other player's behavior (belief elicitation) and their intentions 330 to follow or not the pre-agreements during the game (i.e. pledges before harvest decisions). We 331 define 3 types of subjects based on their mean prediction, beliefs errors: optimistic (belief < 332 others harvest), realistic (belief = others harvest) and pessimistic (belief > others harvest). We 333 also define 3 types of subject's behavior according to their mean responses (harvest decisions) 334 to others' pledge: altruistic (harvest decision < pledges/ (N-1)), consensual (harvest decision = 335 pledges/ (N-1) and free-rider (harvest decision > pledges/ (N-1)). The subject type (Table 3) is 336 a classification of subjects based on their highest frequency belief errors (optimistic, realistic or 337 pessimistic) and intended harvest behaviors (free-rider, consensual or altruistic).

338 Finally, the experimental data, are analyzed with a population average generalized estimating 339 equation model (GEE, developed by Zeger & Liang 1986) with the "geepack" library (Halekoh et 340 al., 2006) available in the programming language R (R Core Team, 2016). The GEE model 341 approach is an extension of the Generalized Linear Model (GLM). It provides a semi-parametric 342 approach to longitudinal data analysis. Longitudinal data refers to non-independent variables 343 derived from repeated measurements. In our experience, we measure repeated decisions of 344 participants which are correlated from one period to another. The GEE model allows an analysis 345 of the average response of a group, i.e. the average probability of making a myopic harvest 346 decision given the changes in experimental conditions, accounting for within-player non-347 independence of observations. The decision of a participant in year t + 1 is linked to his decision 348 in year t, thus violating the hypothesis of independence of the observations formulated in the 349 classical regression methods. For controlling group dependences which occurs trough resource 350 stock and social effects, we performed the same GEE analysis on the average group ratio of 351 harvest decisions over myopic strategies. In this model, we consider that a correlation of the 352 mean group in period t + 1 is linked to the decisions in period t.

The modeling approach also requires a correlation structure, although this methodology is robust to a poor specification of the correlation structure (Diggle et al., 2002). Our dataset consists of a series of successive catch decisions made by a participant during each phase. The grouping variable of the observations is therefore based on each experiment. Since the data is temporally organized, a self-regressive correlation structure (AR-1) is selected. Model selection

- 358 is performed by testing combinations of the covariables (R package MuMIn, Barton, 2014) based
- 359 on Pan's quasi-likelihood information criterion (QIC, Pan, 2001) and individual Wald test.
- 360 We focus our analysis on the ratio of the harvest decision and the myopic harvest strategy. This
- 361 variable, which is a proportion that can be modeled by a binomial distribution with a logit link
- 362 function, specifying a variance of the form: $var(Y_{i,t})=p_{i,t}$. $(1-p_{i,t})$, with $Y_{i,t}=\frac{y_{i,t}}{y^e(B)}$ corresponding to the
- 363 response variable for participant *i* during period *t* and $p_{i,t}$ the probability of the expected value of
- 364 $Y_{i,t}$ ($E[Y_{i,t}] = p_{i,t}$). As for the logistic regressions, we tested for specification errors, goodness-of-fit,
- 365 multicollinearity as well as for influential observations.
- 366

367 <u>Table 3:</u> Description	n of variables used for analysis.
----------------------------------------	-----------------------------------

Variable	Value range	Description
Harvest as a fraction of	R+	Individual harvest decision as a fraction of the myopic
myopic strategy		strategy by period.
Crossing threshold	0 v 1	Group crosses the threshold within 15 rounds.
Belief error (error in other	[-10,10]	Difference between beliefs and the sum of harvest by other participants by period
Intended behavior	[-5 5]	Difference between harvest and symmetric harvest beliefs of
Intended benavior	[5,5]	other participants by period (pledges/(N-1)).
Subject type	[optimistic, realistic,	Classification of subjects based on their highest frequency
	pessimistic, free-rider,	belief errors (optimistic: belief < other harvest, realistic: belief
	consensual, altruistic]	= other harvest and pessimistic: belief > other harvest) and
		intended harvest behaviors (free-rider: harvest > pledges /
		(N-1), consensual: harvest = pledges / (N-1) and altruistic:
		harvest < pledges / (N-1)).
Knowledge index †	[1,5]	Perceived understanding about the resource dynamic
Score test †	[0,3]	Individual score to the understanding test.
† Self-reported variable, obtain	ed from pre and post-experir	nental survey (see Appendix B).

368 **3. Results**

369 **3.1. Overall exploitation management decision patterns**

We found significant differences between treatments (Table 4). First, the threshold treatment groups (T1, T2) cooperate more on average, participants use significantly less myopic strategies and groups deplete significantly less the resource (higher average stock). Furthermore, the groups playing in the threshold treatments which exceed the threshold, experience an important cost that diminishes drastically their profit. We therefore observe a lower average in profit with a high variability between groups. Furthermore, we observe an effect of uncertainty around the threshold (T2). Groups who experience threshold uncertainty cooperate more if we consider the 13

- 377 ratio of harvest decision on the myopic strategy and the mean resource level. However, the
- 378 proportion of groups exceeding the threshold is higher than in the first treatment (T1)⁸.
- 379

380	Table 4: Com	parison of p	proportions and	averages across	treatments.

	Treatment 0	Treatment 1	Treatment 2	p (Kruskal-Wallis test, χ² or
				Fisher's exact test) [†]
Average group harvest as a	0.81 (0.54)	0.65 (0.80)	0.53 (0.72)	0.074*
fraction of myopic strategy				
Average group stock level	20.20 (15.3)	27.80 (13.9)	30.30 (15.8)	0.013*
Proportion of group	-	0.58	0.70	0.68
exceeding the threshold				
Average earning [€] ^x	4.40 (4.62)	2.17 (4.29)	2.15 (3.82)	0.11
Average group profit	10.31 (22.70)	2.90 (29.30)	0.40 (31.54)	0.047*
Average group harvest	1.49 (1.80)	1.54 (1.57)	1.42 (1.60)	0.24
Average group pledge	1.02 (1.48)	1.20 (1.50)	1.26 (1.50)	0.32
Average group belief error	-0.87 (3.00)	-0.66 (2.90)	-0.51 (2.80)	0.53
Average group intended	0.46 (1.70)	0.34 (1.61)	0.16 (1.75)	0.27
behavior				
Average post-	3.90 (1.24)	3.90 (1.10)	4.30 (0.87)	0.27
experimental survey				
understanding index ^{†,v}				
Average pre- experimental	2.00 (1.00)	1.39 (1.00)	1.60 (1.20)	0.04*
_test understanding index ^{†,r}				
Note: Standard errors in brac	kets.			

*Indicates significance p<0.05, ** p<0.01 and *** p<0.001.

† Self-reported variable, obtained from pre and post-experimental survey (Appendix B).

 \uparrow Kruskal-Wallis test is used to compare means across treatments and χ^2 or Fisher's exact test (depending on the case frequencies) used to compare proportions across treatments.

 χ Average earnings (from profits and belief elicitations) doesn't include participation fees.

v Average understanding index is the answer from the post-experimental survey on a five-point Likert scale.

I' Average pre-experimental test understanding index is the score from the 3 pre-experimental questions (Appendix B). A score of 3 indicates a perfect understanding, while a score of 0 a very weak comprehension of the experiment dynamic mechanisms before clarification by the experimenter.

- 382 The overall catch decreasing pattern until the steady state stock size corresponding to the 383 trigger strategy was found similar between groups in the treatment without a threshold (T0, 384 Figure 3). All groups in the treatment T0 followed the trigger strategy and exploited the resource 385 until the stationary non-cooperative equilibrium (10 units). Only 3 groups over 34 managed to 386 maintain the biomass level close to the long term optimal level (40 units), for which the 387 regeneration rate was the highest while the harvesting cost was low. They all belong to the 388 treatments groups (one in T1 and two in T2). 389 In contrast with our theoretical prediction, the majority of groups (7) in the certain thresholds 390 treatments (T1) harvest beyond the threshold. None of these groups is able to reverse the
- 391
- negative trend of stock depletion despite the high penalty cost. We observe the same pattern in
- 392 the uncertain threshold treatment (T2) with 7 cases of exploitation falling beyond the threshold

⁸ We also test the potential effect of playing 2 games (phases) sequentially. We did not find any significant difference between phases using the Mann-Whitney-Wilcoxon test on group averages (Appendix H).

- 393 level. Moreover, despite the high cost related to the full depletion of stocks, two groups have
- intentionally exhausted the resource to end the experiment.
- 395



396

Figure 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

399 uncertainty range around the potential value of B_{lim} in T2.

400

We observe a lower proportion of myopic strategies in the threshold treatments (T1 and T2)
which contradict the theoretical predictions (Figure 4). Moreover, we notice more cooperation
(lower proportion of myopic strategies) in the uncertain threshold treatment than in other
experimental conditions (Table 3). We also clearly discern a time pattern linked with the
scarcity of the resource regardless of the treatment.





411

To go further into the analysis of individual strategies, we show that the more intensive harvest 412 413 pattern (Myopic behavior, Figure 5) in T0 during the first rounds (0 to 8) conduct the stock to B_{tr} 414 (10 units) and zero profits as a result of the application of the trigger strategy. Participants' 415 announcements (pledges) and harvest decisions are helpful to understand the start of the trigger 416 strategy (punishment of free-riders by overexploiting the stock until further depletion becomes 417 unprofitable). During the first rounds in which we observe the highest mean harvest decision, 418 participant's pledges are strictly inferior to harvests conducting participants into intended free-419 riding behavior (intended behavior >0). On the other hand, mean participants' beliefs are too 420 optimistic: they expect other players to harvest less following their announcements (belief error 421 <0). Threshold treatments exhibit the same pattern with a less marked trend in free-riding 422 intended behaviors and prediction of other participants' harvests. The classification into distinct 423 subject types summarizes this information by showing the highest proportion of free-riders and 424 optimistic participants in the experiments (Figure 6). Likewise, this information highlights the 425 high frequency of consensual participant which strengthens the theoretical hypothesis that 426 participants use consensual punishment strategy.



428 Figure 5: Time series of mean harvest and pledge decisions, and mean resulting resource stock
429 size, profit, intended behavior and belief error by treatments (T0, T1 and T2).



431 432

Figure 6: Frequency of subject types for the whole experiments and by treatments (T0, T1 and 433 T2). Classification of subjects based on their highest frequency belief errors (optimistic: belief < 434 other harvest, realistic: belief = other harvest and pessimistic: belief > other harvest) and 435 intended harvest behaviors (free-rider: harvest > pledges / (N-1), consensual: harvest = pledges 436 / (N-1) and altruistic: harvest < pledges / (N-1)).

437 3.2. Exploring predictors for cooperation

438 The selected GEE regression model (Table 5) ⁹ reveals that groups playing the threshold 439 treatment (T1 and T2, p < 0.001) are more cooperative. On average, the odds, ceteris paribus, of 440 behaving myopically in the no threshold treatment (T0) over the odds of behaving myopically in the threshold treatments (T1 or T2) is about 2.56 (inverse of the odds in Table 5). In term of 441 442 percentage of variation, the odds of behaving myopically among the no threshold treatment 443 groups is around 156% higher than groups in the threshold treatment. The threat to cross the 444 threshold enhances cooperation by mitigating selfish behaviors.

445 We can also identify the effect of the resource scarcity on subjects mean harvest decisions. When 446 subjects start experiencing scarcity, they significantly tend to select myopic decisions (biomass 447 level effect, p<0.001). Participants are stuck in short-sighted competitive behaviors. In all 448 treatments, the proportion of myopic decisions increases by approximately a factor 3 to 4 449 between the first and the last rounds of the experiment (Figure 4). This observation is confirmed 450 by the average continuous decreasing trend of biomass throughout time (Figure 3).

- 451 The subject type is also an important explanatory variable which is defined by the ability of
- 452 participants during the experiment to predict other players' behaviors (belief error) and their
- 453 intentions to follow or not the agreement contracted during the game (intended behavior, Table

⁹ We also compared GEE models to random group effect generalized linear models (GLMM with package 'lme4' Bates et al., 2015 in R, Appendix I). The results are qualitatively similar with a higher magnitude of treatment and free-rider participant coefficients.

3). The presence of free-riding participants significantly affects the mean odds of choosing myopic strategies. Those participants who deliberately deviate from the other pledges (catch > pledge/2) selected on average more myopic strategies than other players and lead to stock depletion with the implementation of the punishment (trigger) strategy. Furthermore, the significant positive coefficient of realistic and consensual participants confirms our previous analysis that participants use consensually a punishment strategy.

460

461 **<u>Table 5:</u>** Generalized Estimating Equation regression for the average probability of making a

462 myopic harvest decision.

Binomial regression models	GEE regression Best model	GEE regression Best model	
	Harvest as fraction of myopic	Mean group harvest as	
	strategy	fraction of myopic strategy	
Intercept	1.55*** (0.22)	1.93 *** (0.30)	
Treatment 1	-0.91*** (0.16)	-0.75** (0.24)	
Treatment 2	-0.97*** (0.17)	-1.01** (0.29)	
Biomass	-0.04*** (0.004)	-0.03*** (0.008)	
Player class Consensual ⁺	0.18 (0.20)	_	
Player class Free-rider	0.73*** (0.18)	_	
Player class Realistic	0.40* (0.17)	_	
Player class Pessimistic	-0.06 (0.12)	_	
R ²	0.26	0.31	
AIC/QIC	1810	601	
Correlation structure	AR-1	AR1	
Correlation parameter	0.36 (0.03)	0.41	
Scale parameter	0.59 (0.03)	0.57	
Number of clusters	102	34	
Clusters size	15	15	
Observations	1530	510	

Note: Standard errors are in brackets.

*Indicates significance p<0.05, ** p<0.01 and *** p<0.001.

†Player classes are characterized by both belief errors and intended behavior (harvest decisions) to others pledge (Table 3): Optimistic; Pessimistic; Realistic and Consensual; Free rider; Altruistic.

463 **4. Discussion**

464 The objective of this study was to experimentally investigate the effects that endogenously driven, abrupt changes (i.e. tipping points) of the economic environment may produce on the 465 466 harvest and management decision of the EABFT (a CPR). We found that the existence of a latent 467 and endogenous economic shift significantly influenced resource decision maker strategies regarding management cooperation and resource exploitation. Unlike our theoretical 468 469 predictions (Hypothesis 1), when the threat of a regime shift was present, we observed relatively more cooperative behaviours and a more precautionary management of the 470 471 renewable resources. We also observed more cooperation when the position of the tipping point 472 is uncertain, rejecting our second hypothesis (Hypothesis 2). The threat of substantial losses 473 associated with the shift in economic conditions significantly increased the likelihood of 474 coordinating actions.

475 Our results about the influence of a tipping point on resource exploitation strengthen previous 476 observations by Schill et al. (2015) and Lindahl et al. (2016). They demonstrated that a certain 477 or a highly probable endogenous shift affecting the productivity of the resource creates the 478 condition to avoid a disaster such as a stock exhaustion. Similarly, avoiding an economic disaster 479 in a one-shot public good game with threshold is possible when it is in the interest of each 480 individual (disaster is severe enough) to coordinate and contribute accordingly (Barrett & 481 Dannenberg 2012; Barrett & Dannenberg 2013). But in contradiction with our theoretical 482 expectation, uncertainty around the position of the tipping point influences exploitation 483 strategies, enhancing instead of decreasing cooperation. Deviations from predictions in 484 uncertain decision problems are well known. From empirical evidence, we know that in complex 485 and uncertain decision problems (as used in our experiment), the assumptions underpinning the 486 expected utility theory are questionable (e.g., Tversky and Kahneman 1974). Decision makers 487 typically deviate from expected utility maximization and rely instead on heuristics (Moxnes, 488 1998 and Hey et al., 2009). Such theoretical biases bring insight to our experimental 489 observations which deviate from theoretical predictions and from previous static design results. 490 However, this result challenges previous findings obtained with one-shot public good games 491 under uncertain threshold, in which the uncertainty level around the position of the threshold 492 switches the game outcome from coordination to prisoner's dilemma (Barrett & Dannenberg 493 2013). Observations have shown that participants decreasing their contribution under 494 uncertainty regime to an insufficient level would incur high economic loss and may not avoid the 495 disaster (e.g. cost due to climate change effects, in Barrett & Dannenberg, 2013).

By introducing complex resource dynamics and incomplete information conditions into the experimental design, the focal point represented by the cooperative solution changes over time and is path-dependent. The incentive to deviate from a past agreement increases throughout time, as the probability of a game continuation decreases. Such conditions make cooperation and coordination more unlikely. This has been demonstrated experimentally by Herr et al. (1997) and Mason & Phillips (1997) when comparing static and dynamic designs.

502 Another interesting observation concerns the rare cases of groups (3 cases over 34) maintaining 503 the biomass level close to the long term optimal level (40 units) in our experiment. The 504 complexity and the high competitive feature of the experiment do not allow an agreement to 505 emerge efficiently with only the threat of using trigger strategy. Another explanation of the weak 506 cooperation level in our experiment could be related to the communication which has been 507 reduced to implicit communication through pledges in this experiment. An important factor 508 which has been excluded from our experiment is the introduction of face-to-face 509 communication. Previous CPR research works show that face-to-face communication is 510 important to determine whether groups will cooperate or not (e.g., Ostrom 2006). In complex ecological dynamic experiments, Schill et al., (2015) and Lindahl et al. (2016) have shown that the effectiveness of communication (group agreements), which underlies cooperation, can be endogenous to the decision problem. The latent regime shift that people perceive as a threat in their experiments seems to be the trigger of communication between subjects.

515 Finally, we found a clear trend of non-cooperative (myopic) strategies over time regardless of 516 the treatment. We found a strong correlation between non-cooperative strategies and the 517 scarcity of natural resources. Subjects are prone to competitive and more intensive fishing behavior when the resource becomes scarcer. More surprisingly, the high cost of exceeding the 518 519 threshold does not affect this pattern. This result confirms previous findings by Osés-Eraso et al. 520 (2008). They had observed that users responded to scarcity with caution by observing directly 521 harvest levels but were, nevertheless, not able to avoid resource extinction. If we observed 522 directly the harvest instead of the ratio between harvest and the myopic harvest level, subjects 523 would have decreased their catch levels. But the latter do not represent a good indicator of the 524 cooperation level. When the situation becomes more competitive, with fewer natural resources 525 to share, participants' behaviors seem to be driven by myopic strategies.

526 Our experiment is set in the context of the international management of a highly migratory fish, 527 the Atlantic Bluefin tuna (EABFT) fishery and reproduces a stylized representation of the 528 decision making process in the International Commission for the Conservation of Atlantic Tunas 529 (ICCAT), to the notable exception of communication exchanges between participants. Our results 530 confirm the possible change of management behaviours confronted to the threat of a shift in 531 economic conditions. This situation is somehow close to the context of trade ban in 2009 532 jeopardizing the future of the EABFT fishery, which has resulted in a dramatic decrease of 533 quotas (TACs) accepted by the fishing nations. When a critical threshold is introduced, decision 534 makers coordinate their efforts in order to avoid exceeding the potential threshold, becoming 535 more efficient, decreasing the rent dissipation and improving the sustainability of the resource. 536 We know from previous CPRs experiments the importance of direct communication in the 537 setting of cooperative agreements between participants (i.e Schill et al., 2015 and Lindahl et al., 538 2016). We leave to future works, the analysis of direct communications on cooperation in our 539 CPR dilemma. It is worthwhile noting that our results stem from laboratory experiments with 540 students as subjects. To increase confidence in our results, a next step would be to replicate this 541 design into the "battle field", i.e. an international central institution such as the ICCAT 542 commission with actual policy makers.

543 **5. Acknowledgments**

We are thankful for valuable comments received from Marc Willinger, Stefano Farolfi, Dimitri
Dubois, Nils Ferrand, Sander De Waard, members of the Laboratoire d'Economie Expérimentale

- de Montpellier (LEEM) working group and members of the IM2E Experiments on Uncertainty
 and Social Relations workshop. We thank Julien Lebranchu for his computer support, Dimitri
 Dubois for his experiment assistance and Anne-Catherine Gandrillon for her language
 corrections. We are also thankful for valuable comments received from two anonymous
 reviewers. Finally, we acknowledge the financial support of the COSELMAR project (funded by
 the Regional Council of Pays de la Loire) and from the University of Nantes and IFREMER for the
- 552 funding of a PhD. Last but not least, we would like to thank our experiment participants.

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659 7. Supplementry materials

660 **7.1. Appendix A. Instructions.**

661 Instructions T0

It is an experiment dealing with economic decision-making. We ask you to carefully read the instructions. When all the participants have read these instructions an experimenter will proceed to a re-reading aloud. We will then ask you to watch attentively a tutorial video to familiarize yourself with the web interface of the experiment.

From now on, we ask you not to speak anymore. If you have a question raise your hand and an
experimenter will come to answer you privately. During the experiment, all your decisions will
be treated anonymously. You will indicate your choices on the computer in front of which you
are seated.

670

671 General instructions

This experiment has two parts. These instructions concern both parts 1 and 2 of the experiment.
One of these two parts will be chosen by drawing lot for your remuneration. Your earning at this
game will constitute your gain for the experience. It will be paid in cash at the end of the
experiment.

In this experiment, each of you is a policy maker of a country involved in the East Atlantic bluefin tuna fishery. You and 2 other participants will form a group. You and your group members will have a common access to the Atlantic bluefin tuna resource. Each of you, at each round (which represents one year), will decide how many units (tons) of the resource you would like to harvest. These catches will bring you earnings in units of profit (euros).

Before making your decision, you will have to announce your catch to the other players, without
the latter engaging you in your future private decision: you will be able to follow it or not. At the
same time, you will also estimate the cumulated catches of the

- other 2 members of your group. Finally, to make your private
 catch decisions, you will have access to catch proposals from
 other members of your group as well as information on the
- 687 state of the resource from the International Commission for the
- 688 Conservation of Atlantic Tunas (ICCAT).
- Each part of the experiment lasts a certain number of rounds(years in the experiment), the amount of rounds is unknown toyou. The experiment also ends if the resource is depleted due to
- 692 excessive catches.



693

694 **Remuneration**

- If you follow the instructions carefully and take sound decisions, you can earn money. One of the games will be chosen by drawing lot for your remuneration. Your earning at this game will constitute your gain for the experiment. Each profit you have accumulated by exploiting the resource during each game separately will be converted into euros at a rate of 1 monetary units of profit = $0.05 \in$. You will begin each part of the experiment with 50 profit units, corresponding to $2.50 \in$. You will also be compensated for your exact expectations of the catch levels of the other participants, $0.20 \in$ for each exact expectation.
- 702

703 **Resource dynamic**

The bluefin tuna resource increases in each round depending on the size of the resource at the beginning of the round, which in turn depends on the total harvest of the previous round (sum of your and the other participant's harvest in the previous round).

707 The exact relation between the size of the resource stock and its regeneration is illustrated in 708 Figure 1. As the figure illustrates, if the total amount of catches exceeds the regeneration rate for 709 the round, the resource stock will decline. Contrariwise, if the total amount of catches is inferior 710 to the regeneration rate for the round, the resource stock will increase the next round. The 711 Maximum Sustainable Yield (MSY) indicated on the figure (from 28 to 42 resource units) is the 712 maximum amount of catch that allows the stock to remain constant from one round to the next. 713 For example if the resource stock is 50 units of the resource at the beginning of a round. If you, 714 harvest together with the 2 other members of your group 10 units in this round, the resource

will regenerate itself by 2 units and, hence, the resource stock will be (50 + 2 - 10) 42 units in the

- next round.
- 717

718 Harvest choice

Each round, you will receive information about the resource stock size available and harvest
proposals from the 2 other members of your group. Depending on the part of the experiment the
information about the resource stock size will be accurate or not. If this information is not

accurate you will be aware of a range of equal possible value of

- the resource stock size each round for which you can deduceyour possible profits.
- Based on this information, you will choose how many units of
 resource you would like to harvest with a choice between 0 to 5
 units. You, and the 2 other members of your group could harvest
 each round a total of 15 units. This amount of catch will bring
 you earning which depends on your harvest level, but also on the



730 harvest level of the 2 other participants and on the resource stock size. The relation between 731 your profit, the total amount of catch from your group and the resource stock size is illustrated 732 in Figure 2. As illustrated in Figure 2, the most the resource is depleted the less you could earn 733 from harvest. 734 Your harvest decision is private but will be made public at the end of each round. 735 736 Some rules 737 • Talking is not permitted. 738 • You are not permitted to operate other software such as email or web pages during the 739 experiment. 740 • You may ask questions to the experimenter during the experiment if you have any 741 problems. 742 Before starting the experiment, you will be invited to follow a tutorial video presenting the web 743 interface of the experiment. Once this video has been watched, you can then complete the 744 identification form on the application page and fill in the comprehension test. Once the test has 745 been completed, you will have the opportunity to ask questions about the elements of the 746 experiment. Finally, at the end of the experiment, you will have to complete a short survey about 747 the experiment, and then you will have to wait until the experimenter calls you individually to 748 receive your payment. 749

750 **7.2. Appendix B. Pre-experimental survey and test.**

About you

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Time left to comple efore beginning the rst of all, if at the be ar? Use the growth esource growth in usen, still with a stock ar? Use the profit fr stal profit in 10^7 e	te this page: O 4:51 session, We want to make sure that you understand the dynamic process which drive the resource level. ginning of the year the biomass is at a level of 2510 ⁴ t, could you indicate how many units (in 10 ⁴ t) the stock will grow for the ne function. 10 ⁴ t for the year: : of 25 10 ⁴ t if the 3 nations decide to harvest 9 10 ⁴ t, could you indicate how many profit (in 10 ⁷ €) the harvest will generate this inction and round the value. : for the year:
Test Time left to complete efore beginning the rst of all, if at the be ear? Use the growth esource growth in hen, still with a stock ear? Use the profit in tal profit in 10^7 e inder the same cond dividual profit)?	te this page: ⊙4:51 session, We want to make sure that you understand the dynamic process which drive the resource level. ginning of the year the biomass is at a level of 2510 ⁴ t, could you indicate how many units (in 10 ⁴ t) the stock will grow for the ne i function. 10^4 t for the year: c of 25 10 ⁴ t if the 3 nations decide to harvest 9 10 ⁴ t, could you indicate how many profit (in 10 ⁷ €) the harvest will generate this inction and round the value. c for the year: tions, if the 3 nations decide to harvest 9 10 ⁴ t (3.0 10 ⁴ t each), Could you indicate how many profits in 10 ⁷ € you will win this ye that a coffe

751 752

29

Next

753 7.3. Appendix C. Payoff and stock (biomass) variation table used in the experiment for
 754 a resource size of 50 units. On the top the "Payoff table" and on the bottom the





758 **7.4. Appendix D. Harvest results and stock (biomass) projection example.**

Results from harvest

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You have selected an harvest of 0 (10⁴ t). Your profit for the last year is 0.0 (10⁷ \in).

Your total profit since the beginning of the fishery is 0.0 (10⁷ \in).

This is equivalent to a real payment of 0.0 Plus a bonus payment for your expectations of the level of exploitation of other nations of euros $0.20 \in$. ICCAT commission gives you also the statistic from the total catch and profit realized last years.





761 **7.5. Appendix E. Relationship between the optimal stock level (***B_{opt}***) and the discount**



20

15

10

5

0

0.7

0.75



0.8

0.85 δ

0.9

0.95

1





768 **7.7. Appendix G. Myopic symmetric paths.**

Considering that all participant have the same payoff function, we restrict the analysis to symmetric outcomes in which each participant uses the same harvests strategy y^e). In this context a participant *i* seeks to maximize his profit flow by selecting an harvest strategy. Letting δ represent the discount factor, common to all participants, the present discounted value of profit in period *t*, $V_{i,t}$ of each participant, satisfies the Bellman's recursion equation:

774
$$V_{i,t} = Max_{y_{i,t}}(\pi_{i,t} + \delta. V_{i,t+1})$$
(H1)
775 $s.t B_{t+1} = B_t \cdot \left[1 + r \cdot \left(1 - \frac{B_t}{K}\right)\right] - (N-1) \cdot y_t - y_{i,t}$

$$y_t = y^e(B)$$

776 Myopic behaviors result from neglecting the fact that current extraction decreases the future 777 value of the resource is defined by backward recursion of the Bellman equation H1 considering 778 the discount factor δ which tends to 0. Therefore, we define the collective (*N* participants) 779 myopic path for each experimental treatment: without tipping point, when a tipping point is 780 introduced and when the position of the tipping point is uncertain (on the left, middle and on the 781 right respectively). We consider risk-neutral players when the position of the tipping point is 782 uncertain. The risk neutral players based their harvest strategy upon the following profit 783 function:

$$\pi_{i,t} = \begin{cases} p. y_{i,t} - C(B_t). \frac{y_{i,t}}{Y_t}, \text{ for } B_t > B_{lim}^{max} \\ p. y_{i,t} - C(B_t). \frac{y_{i,t}}{Y_t} - \alpha. \left[1 - \left(\frac{B_t - B_{lim}^{min}}{B_{lim}^{max} - B_{lim}^{min}} \right) \right], \text{ for } B_t \in [B_{lim}^{min} B_{lim}^{max}] \end{cases}$$
(H2)
$$p. y_{i,t} - C(B_t). \frac{y_{i,t}}{Y_t} - \alpha, \text{ for } B_t < B_{lim}^{min}$$



Round (vear)

785

7.8. Appendix H. Phase effects.

	Phase 1	Phase 2	p (Mann-Whitney-Wilcoxon test,χ² or Fisher's exact test)†
Average group harvest as a	0.68 (0.67)	0.67 (0.74)	0.92
fraction of myopic strategy			
Average group stock	25.94 (15.41)	25.75 (15.71)	0.87
Proportion of group crossing	0.64	0.64	1.00
the threshold			
Average group profit	4.60 (28.17)	5.00 (28.22)	0.92
Average group harvest	1.49 (1.64)	1.48 (1.70)	0.97
Average group pledge	1.19 (1.52)	1.12 (1.47)	0.49
Average group belief error	-0.67 (2.89)	-0.70 (2.92)	0.81
Average group intended	0.30 (1.68)	0.36 (1.69)	0.65
behavior			

Note: Standard errors in brackets.

*Indicates significance p<0.05, ** p<0.01 and *** p<0.001.

 \uparrow Mann-Whitney-Wilcoxon test is used to compare means across phases and χ^2 or Fisher's exact test (depending on the case frequencies) used to compare proportions across treatments and phases (see Appendix 6 for information on statistical analysis).

7.9. Appendix I. Random effect generalized linear mixed model (GLMM) regression.

Binomial regression models	Random group effect GLMM	Random group effect GLMM
Dinomial regression models	regression	regression
	Rest model	Best model
	Harvest as fraction of myonic	Mean group harvest as fraction
	strategy	of myonic strategy
Intercent	1 40 *** (0 28)	2 45 *** (0 31)
Treatment 1	-1 32*** (0.30)	-1 19** (0.48)
Treatment 2	-1 39*** (0.32)	-1 31** (0 51)
Riomass	-0.05*** (0.005)	-0.05*** 0.008)
Player class Consensual [†]	0 47* (0 22)	0.05 0.000
Player class Free-rider	1.10*** (0.18)	-
Player class Realistic	0.52* (0.27)	-
Player class Pessimistic	0.38* (0.18)	-
R^2	0.27	0.26
AIC/OIC	1676	578
Number of clusters	34	34
Clusters size	45	15
Observations	1530	510
Note: Standard errors are in brackets.		
*Indicates significance p<0.05, ** p<0.01 ar	nd *** p<0.001.	
5 I · I	•	