Cascading Defections from Cooperation Triggered by Present-Biased Behaviors in the Commons

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Abstract:

This work shows that defective behaviors from the cooperative equilibrium in the management of common resources can be fueled and triggered by the presence of agents with myopic behaviors; a similar phenomenon is also possible with cooperative motivations.

This paper demonstrates and discusses that the apparent and detectable decay of the cooperative choices in the dilemmas of common resources are not an exclusive and indisputable signal of an escalation in free-riding intentions, but can also be an outcome of the present-biased preferences and myopic behaviors of the cooperative agents.

In fact, within the context populated by conditional cooperators with a heterogeneous myopic discount factor, in the absence of information about agents' intentions, the present-biased preferences can trigger a strategy that directs the community to excessively increase its harvesting level, even in presence of the other-regarding motives.

The behavior implemented by naïve agents, even if done with cooperative intent, can activate a dynamic of cascading defections from the cooperative strategy within the harvester group. Therefore, a lowering of the cooperative behaviors can also be the effect of the absence of coordination instruments in response to the cognitive bias that influences human behaviors.

Keywords: Present bias, Commons, Cooperation, Cascading Defections, Naïve Agent.

JEL Classification : C71, C73, D03, D90, Q20, Q29.

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Contents

1. Introduction

In the task of managing common resources, one of the main issues that a community faces is avoiding the trigger of the tragedy of the commons. A not-collapsing management of the commons greatly depends upon the cooperative capacities of the communities and their ability to maintain the cooperation inside the group over time. This study will show when and in what manner there is involvement of present-bias in the triggering of strategies that contribute to non-cooperative behaviors in common harvesting.

Cooperative behaviors have been largely investigated in behavioral economics (Fehr and Gächter, 2000; Gächter, 2007; Sally, 1995), and other-regarding and social preferences are found in everyday life (Gintis, 2000), in a wide range of situations (Alpizar et al., 2008; Frey and Meier, 2004; Meier and Stutzer, 2008) and within different cultures (Henrich et al., 2005). However, in the presence of social preferences, when individuals participate in a common pool resources or public good game, in the absence of coordination and enforcement instruments or institutions, there is frequently a decay of cooperative behaviors (Andreoni, 1988; Dawes and Thaler, 1988; Fehr and Schmidt, 1999; Gintis, 2000; Gintis et al., 2003; Isaac et al., 1994; Ledyard, 1994). When individuals cooperate only when others also cooperate (conditional cooperators), the presence of free-riders, or individuals without full cooperative behaviors, can trigger a dynamic of defection by cooperation (Fischbacher et al., 2001; Fischbacher and Gächter, 2010). However, when resource management includes specific intertemporal peculiarities with relevant externalities, resource harvesting is vulnerable to the risks of inefficiency in intertemporal management, as it results from the difficulties that people often encounter in defining intertemporal choices and allocating consumption in a consistent manner. This phenomenon refers to the existence of present-biased preferences. In fact, individuals, due to their impulsivity, follow short-term benefits without considering adequately the long-term consequences, particularly in situations in which the individuals systematically behave by discounting the near future more than the distant one (Loewenstein and Prelec, 1992). These behaviors reveal the lack of self-control in the face of the pressure of the present (Laibson, 1997; O'Donoghue and Rabin, 1999); so, when there are present-biased preferences, the immediate benefit directs the choices despite the long-run interest. This is true also in the case of a social dilemma. In Herr et al. (1997), for example, participants interact in a common pool resource experiment that reveals a lower efficiency when the experimental design provides intertemporal externalities, manifesting fundamental short-sighted behaviors. Participants, in fact, do not adequately consider the future consequences of their decisions, and they show short-sighted behaviors in dynamic games (Pevnitskaya and Ryvkin, 2013).

Myopic behavioral patterns are particularly dangerous in the context of common resources because they can generate rapid resource depletions. Generally, common resource dilemmas are defined within a context in which the long run choices and short ones can conflict, thus exposing the resources to the risks derived from present-bias. Thus, the role played by present-bias in the decay dynamics of cooperation in the commons could be consistent with the systematic decline of the cooperative propensity with the passage of time. In fact, one of the salient elements that is present in the common resource experiment is the progressive decay of the cooperative behaviors with the advancement of the interactions between the agents (Ostrom, 2000).

When resources are commons with intertemporal harvesting peculiarities, the decay of cooperation intentions can be the main obstacle to the preservation of a given stock of resources. With the consequence of the reduction in the community welfare, hence it is clear why the decay of cooperation in the commons has so much relevance. However, in this context, the role played by the cognitive biases is not adequately investigated. The questions of if and in what manner such phenomena like present-bias can affect the dynamics of the cooperation and its eventual decadence have yet to be raised. It is also remarkable that even though it is beyond any doubt the existence of cooperation capability as part of the human evolutionary success (Gintis, 2009), it is unclear why societies sometimes fail to achieve the level of fairness and cooperation that they desire.

Therefore, this work presents a representation of human behaviors that do not exclude these cognitive foundations of the process of decision-making in the intertemporal context. Without the necessary inclusion of the intertemporal cognitive features of human behavior, the models used to describe the human phenomena in resource harvesting are unable to include the real issues that can trigger the defective strategies from cooperation in the management of the common resources generating overexploitation.

2. Present bias and why take care of it in the commons

Present-bias refers to behaviors that result from the duality of the discount rate in short-term and long-term periods that determine a non-consistency time behavior in tasks that require intertemporal planning. Time inconsistency implies that an optimal choice defined at the present could be revisited in the future (Strotz, 1955). The present bias thus determines the emergence of preference reversals that generate a conflict between long run preferences and immediate choices, resulting in a conflict between the early intention of the agent and the choice made at the moment. The genesis of these phenomena has a solid cognitive foundation. In fact, it is noteworthy that researchers in the fields of cognitive neuroscience support a non-constant discount rate finding two ways to process the discounting: one for the immediate rewards and another for the delayed ones.[1] Experiments reveal an activation of the limbic circuit just prior to the choices that provide an immediate reward (McClure et al., 2004). Similar conclusions

[1] Two distinct brain areas are involved in the definition of intertemporal choices. The first area, the limbic and paralimbic, is a brain region heavily innervated by the dopaminergic system and connected to rewards expectation (Breiter and Rosen, 1999; Knutson et al., 2001; McClure et al., 2003), while the other area belongs to the front-parietal region, an area that supports the higher cognitive functions (Loewenstein et al., 2008).

were also drawn by Hariri et al. (2006), and McClure et al. (2007).[2] The joint involvement of two systems in decision-making processes is further supported by Bechara (2005), Bechara et al. (1999), Damasio (1994) and LeDoux (1996); therefore, for consumer choices defined in an intertemporal context, the dualism between the limbic system and the deliberative-cognitive system of the neocortex highlights a distinction between the reactions in responses to short and long-term stimuli. Where information regarding immediate rewards is mostly subjected to processing by an impulsive system, instead a more appropriate reflective system refers to decisions regarding long run rewards. It is possible to assert that the present bias is an element of the decision processes deeply rooted in human nature, in several areas of the individual's life. In fact, the present biased behaviors are also clearly evident in several situations (Della Vigna, 2009; Frederick et al., 2002; Thaler, 1981) and different contexts, such as the low saving rate (Ashraf et al., 2006; Harris and Laibson, 2001; Laibson, 1997; Laibson et al., 1998), health choices (van der Pol and Cairns, 2002), drugs, smoking or buying addictions (Frederick et al., 2002; Gruber and Koszegi, 2001; Thaler and Shefrin, 1981; Wertenbroch, 1998), and procrastination behaviors (Benabou and Tirole, 2003; O'Donoghue and Rabin, 1999). The unifying factor in all these fields is the contrasting dichotomy between long-term well-being and immediate enjoyment, this dichotomy characterizes the emergence of present biased behaviors. Present-bias seems, therefore, to be a specific peculiarity of decision heuristics on intertemporal choices in frameworks where long-term plans can be subject to revision and where the

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[2] The limbic circuit is the seat of the emotional reaction processes (Hariri et al., 2000) and impulsive behaviors (Pattij and Vanderschuren, 2008); in fact the limbic system - the most ancient part of a human's brain – also includes the amygdala (Isaacson, 1974), whose functions are closely related to emotional activities (Cardinal et al., 2002; Hariri et al., 2002). Vice versa, a second area that it is afferent to the neocortex, the most recently formed brain area from an evolutionary perspective, shows prevalent activation in correspondence of actions that are the outcome of choices that take future gains into consideration best. This second area, exclusive to mammals and distinctly developed in humans (Rachlin, 1989), plays a key role in appropriate deliberative-cognitive activities.

long-term outcomes depend upon a continuum of instantaneous or short-term choices. This feature also defines the framework of common resource dilemmas. In fact, the intertemporal management of the commons has the characteristics of the framework in which the long-term and short-term choices can conflict, exposing the resources to the risks that are come from present-bias. In the fields of the resources exploitation the present-bias and naïve behaviors could prove very dangerous for the maintenance of the resources, in fact in the absence of time consistency, an undesired collapse of the natural resources could occur (Hepburn et al., 2010). Hence, when a conflict arises between the short and long-term interests, as in the management of common resources, present-biased preferences are likely to play an important role.

It is well known that the commons is a field in which the relevant elements of human choosing are not limited to the area of intertemporal resources management, but also one in which human sociality plays a crucial role. On one hand, the adoption of sustainable and cooperative behavior in relevant social dilemmas depends on the degree of consciousness about the effect of their own behaviors on others, and on the common resources; this inclination finds form in cooperative and other-regarding motives. On the other hand, the choices made reflect the capability of correctly reading and weighing the costs and benefits that result from one's own choices. The intertemporal decision-making processes that involve present biased preferences directing these choices are also the paths by which individuals solve social dilemmas. Within this process cooperation also finds realization. For these reasons, the cooperative and intertemporal dynamics need to be analyzed together.

The contributions to understanding the role of other-regarding preferences in social dilemmas are abundant in the literature and reveal that the cooperation and fairness principle contributes in the formulation of the agent's choices (Fehr and Gächter, 2000; Gächter, 2007; Ostrom et al., 1994). Several works have investigated the true foundations of economics when the actors make decisions within a social context, showing with undisputed clarity that the individual's decisions are mediated by other-regarding motives and by prosocial concepts like fairness, cooperation and reciprocity

(Andreoni, 1990; Bolton and Ockenfels, 2000; Charness and Rabin, 2002; Falk and Fischbacher, 2006; Fehr and Schmidt, 1999; Rabin, 1993). Furthermore, the consequences of the introductions of the other-regarding preferences in the theoretical frameworks on the management of the commons draws great attention and offers additional elements of analysis for applications in environmental and resource issues (Brekke and Johansson-Stenman, 2008; Carlsson and Johansson-Stenman, 2012; Gowdy, 2008; Gsottbauer and van den Bergh, 2011; S. Frey and Stutzer, 2006). Additionally, in the specific field of commons several analyses and investigations have confirmed the ability of human beings to voluntarily sustain the cooperation in resources dilemmas (Casari and Plott, 2003; Charness and Villeval, 2009; Chaudhuri, 2011; Fehr and Leibbrandt, 2011; Ledyard, 1994; Ostrom et al., 1992).

However, we cannot merely emphasize the presence of the cooperative will of individuals; there is also a need to truly comment on the frequent observations, especially in the field of controlled experiments, of a systematic decadence of cooperative propensity over time and with the prosecution of the interactions among the agents (Ostrom, 2000). The reason for the decay of the cooperation propensity over time is an argument of discussion and great interest. This decay is of great relevance, not merely theoretically, but also from the applied perspective: it is known that when confronted with resources, which are intrinsically commons and having an intertemporal harvesting peculiarity, the decay of the cooperation instances can become the main obstacle to the preservation of a given stock of common resources over time and generations. However, in this context, the part played by the cognitive biases has not been adequately explored. If and in which manner phenomena such as present-bias can affect the dynamics of cooperation and its eventual decay continues to remain unclear. But, as it has been discussed here, the dynamics of harvesting in the commons has a double determination that involves both the cognitive and social spheres, two spheres that are defined as one in the intertemporal decision-making processes and the other in the cooperative attitude. So the role played by present-biased preferences in the decay of cooperation must be clarified, showing that shortsighted behaviors deriving from present-bias can be involved in a decadence of cooperative interactions over time and within a framework that includes common resources, even when agents have preferences for cooperation. Therefore, in the following sections it will be shown the manner in which the present-bias is involved in the triggering of strategies that contribute to a non-cooperative behavior in common harvesting, determining cascading defections.

3. Harvesting model and baseline emerged behaviors

The model concerns the activity of harvesting from a stock of non-perishable resources, a discrete time framework is considered where the stock of resources at time t is $R(t)$ with $0 \leq t \leq T$ and $T \neq \infty$, and the quantity harvested is expressed as $h(t)$. The fundamental equation that determines the dynamics of the growth of the resources subject to the harvesting is as follows:

$$R(t+1) - R(t) = f\big(g, R(t)\big)R(t) - h(t), \tag{1}$$

where the growth rate, $f\big(g, R(t)\big)$, is not negative.[3] In the case in which the stock size does not affect the growth rate, the resource stock grows at a constant and strictly positive exponential rate equal to g, such that:

$$f(g, R(t)) \geq 0 \text{ and } g > 0 \text{ with } t \in [0, T], \tag{2}$$

and

$$\text{if } \frac{\partial f(g,R(t))}{\partial R(t)} = 0 \ \rightarrow R(t+1) - R(t) = \big(g - \hat{h}\big)R(t) \ \text{ with } \hat{h} = \frac{h(t)}{R(t)}. \tag{3}$$

The time interval from 0 to T is the finite lifetime of a single agent. Moreover, the initial stock of resources and the growth rate are known by all the agents.

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[3] The non-negative growth rate derives from the non-perishability of the resources.

The initial stock at time zero is strictly positive. It is assumed that resources are material; therefore, negative stock of resources is not possible:

$$R(t) \geq 0 \text{ with } R(0) = R_0 \wedge R_0 > 0 \quad \forall\ t \in [0, T]. \tag{4}$$

The amount harvested at time *t* by the agent, $h(t)$, is not restorable, therefore,

$$h(t) \geq 0\ \ \forall\, t \in [0, T]. \tag{5}$$

The agent faces a capacity constraint: in each period he cannot harvest more than h_{max}, a value that is strictly positive and finite, and thus, together with the non-negativity constraint, is expressed as:

$$0 \leq h(t) \leq h_{max} \quad \forall\ t \in [0, T] \quad \text{with} \quad h_{max} > 0 \text{ and } h_{max} \neq \infty. \tag{6}$$

Furthermore, each agent also faces a resources constraint such that he cannot harvest at time *t* more than the stock of resources available in that moment:

$$h(t) \leq R(t) \quad \forall\, t \in [0, T]. \tag{7}$$

Both the capacity and resources constraints are assumed to be exogenous and equal for all the agents.

The model assumes only material resources and no exchange market; hence, the welfare of the agents depends only on the amount of resources harvested and enjoyed at the time of harvesting, so the lifetime utility of the agent evaluated at time 0 is:

$$U = \sum_{t=0}^{T} \delta(t)\, u(h(t)). \tag{8}$$

The agent's preferences are monotonic and strictly concave on the amount harvested:[4]

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[4] In this way the existence of a unique optimal solution is guaranteed.

$$u'(h_t) > 0 \quad u''(h_t) < 0 \quad \forall\, h \in \mathcal{R}^+. \tag{9}$$

The discount factor $\delta(t)$ represents the degree of impatience on harvesting. Agents exhibit impatience on the harvesting time such that $\delta' < 0$,[5] so the discount factor is monotonic and decreasing over time with:

$$\delta(t) > \delta(t+1) \;\; \forall t \in [0, T]. \tag{10}$$

To summarize the problem of the optimal harvesting path, the agent maximizes the utility function (8) under the constraints expressed in (4), (6) and (7) when the initial condition and the natural growth rate respect the non-negative constraints and the dynamic of resources' growth respects (1).

So, assuming continuity for the harvesting amount on the interval [0, h_{max}], given the discount factors $D=\{\delta(0), \ldots, \delta(t), \ldots, \delta(T)\}$ that respect the peculiarity just enounced, it becomes clear that in the agent's lifetime, at any time $t \in [0, T]$, there is just one optimal solution for the problem of maximization that the agent has to face.

Of course, the intertemporal harvesting plan depends upon the form of the discount factor, in particular if it is expressed in an exponential way that guarantees time consistency, or if the agent has some other form of discount that generates time inconsistency such as, in our case, the present bias.

Hence two possible and alternative outcomes from the process of optimization are considered. The first is the no-bias optimal harvesting strategy expressed as:

$$H_{opt} = \{h_{opt}(0), \ldots, h_{opt}(t), \ldots, h_{opt}(T)\}. \tag{11}$$

The no-bias optimal harvesting strategy, H_{opt}, is the strategy defined when the discount

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[5] With this assumption, the case of pleasure in procrastination, $\delta'(t)>0$, is excluded.

factor of the agent is expressed in an exponential manner that guarantees time consistency.[6] H_{opt} also corresponds to the long-run optimal harvesting plan for the agent (O'Donoghue and Rabin, 2002). It is clear and trivial, that in presence of time consistency, the agent does not vary his optimal strategy with the passage of time.

The second possible outcome of the process of optimization, the biased harvesting strategy H_{bias}, takes place when time inconsistency is assumed. Time inconsistency implies that the discount factor of the agent is not constant over time, so it is assumed that:

$$\begin{cases} \frac{\delta_t}{\delta_{t+1}} > \frac{\delta_s}{\delta_{s+1}} \quad \text{with } t < s \text{ and } s \in [0,T] \text{ for } t = 0, \\ \frac{\delta_t}{\delta_{t+1}} \geq \frac{\delta_s}{\delta_{s+1}} \quad \text{with } t < s \text{ and } t,s \in [0,T] \text{ for } t > 0. \end{cases} \tag{12}$$

The consequences of a no constant discount factor can be defined here.

Postulate 1: If it is solved at time t, $t < s$, with $\frac{\delta_s}{\delta_{s+1}} = \frac{\delta_{s+1}}{\delta_{s+2}}$, the problem of intertemporal optimization in the interval $[s,T]$, with an existent unique optimal solution:

$H_t = \{E[h(s)]_t, \dots, E[h(s+1)]_t, \dots, E[h(T)]_t\}$, where $E[h(s)]_t$ is the expected harvesting amount for time s; and at time s, the same optimization problem is solved in the interval $[s,T]$ with the following optimal solution:

$H_s = \{h(s), \dots, E[h(s+1)]_s, \dots, E[h(T)]_s\}$; when $E[h(s)]_t < R(s)$ and $E[h(s)]_t < h_{max}$ if a time s $\frac{\delta_s}{\delta_{s+1}} > \frac{\delta_{s+1}}{\delta_{s+2}}$ with $\frac{\partial \delta}{\partial t} < 0$, then $h(s) > E[h(s)]_t$.

[6] Agent has no biased preferences when $\frac{\delta_t}{\delta_{t+n}} = \frac{\delta_s}{\delta_{s+n}}$ $\forall\, t \in [0,T]$ and $\forall\, s \in [0,T]$. Only when the discounting respects this condition can the agent's evaluation of the optimal strategy in every period s between 0 and T conducts to the same optimal harvesting strategy evaluated in any period t in $[0, T]$.

So, as anticipated, the agent can be present-biased and, in this case, the biased harvesting strategy can be expressed as:

$$H_{bias} = \{h_{bias}(0),\dots,h_{bias}(t_b),\dots,h_{bias}(T)\}. \tag{13}$$

H_{bias} is derived from the instantaneous maximization at each time of the utility of the agent as well the H_{opt}; but, in contrary to the case of no-bias optimal harvesting strategy the discount factor incorporates the present-bias peculiarities expressed in (12) under the constraints expressed earlier.[7] The consequences can be synthetized in the following:

Lemma 1: Given an expected harvesting amount formulated at time t, $h_{opt}(s) > 0$, with $t < s$, t and s in $[0,T]$ and $h_{opt}(s) < h_{max}$, under the assumption of present bias defined in (12), if $R(s) > h_{opt}(s)$ and $R(s)=E[R(s)]_t$, where $R(s)$ is the resources stock at time s and $E[R(s)]_t$ is the expected stock estimated at time t, then at time s the agent harvests an amount greater than the amount predicted for the same period in the optimal strategy formulated at time t, $h_{opt}(s)$, that could be harvested in absence of bias:

$$h_{bias}(s) > h_{opt}(s) \text{ with } h_{opt}(s) \in H_{opt} \text{ and } h_{bias}(s) \in H_{bias}. \tag{14}$$

In fact, when $R(s)=E[R(s)]_t$, referring to the time interval $[s, T]$ at time t for the no-bias condition, the agent will face the same situation faced at time s, but under the bias condition. So it will be that $H_{opt} \succ H_i$ at time t, where H_{opt} is the optimal harvesting plan evaluated at time t and H_i is any other harvesting plan different from H_{opt} in the set of all possible plans, and H_{opt} is defined under the hypothesis of an exponential discount such that $\frac{\delta_s}{\delta_{s+1}} = \frac{\delta_{s+1}}{\delta_{s+2}}$ with $\frac{\partial \delta}{\partial t} < 0$ and, $h_{opt}(s) \in H_{opt}$. But $H_{bias} \succ H_i$ at time s with $\frac{\delta_s}{\delta_{s+1}} > \frac{\delta_{s+1}}{\delta_{s+2}}$ and $\frac{\partial \delta}{\partial t} < 0$, hence at time s the situation expressed in the postulate 1 takes

[7] It is notable that both the hyperbolic that quasi-hyperbolic discounts respond to the properties defined.

place, so because $h_{opt}(s) < h_{max} \wedge h_{opt}(s) < R(s)$ it will be $h_{bias}(s) > h_{opt}(s)$.

So, given a context in which it is effectively possible to assist in a reduction of the stock of resources, the existence of present-biased preferences could move out the harvesting path. This context is characterized by a situation in which it is not possible for the agents to avoid a total exploitation of the resources before the end of the periods if they harvest continuously the amount h_{max} in the interval $[0,T]$. It is obvious that this is the context in which the agent is called to determine a harvesting plan in which there is the following condition:

$$R_0 + \sum_{t=0}^{T-1} \Big[[R(t) - h(t)] \cdot f\big(g, R(t)\big) \Big] - \sum_{n=1}^{N} \sum_{t=0}^{T-1} \left[h_{max} \cdot \Big(1 + f\big(g, R(t)\big)\Big)^{t} \right] \leq 0, \tag{15}$$

where N is the number of agents that harvest from the stock.

The (15) implies that there is at least in one period where $h(t) < h_{max}$, then considering that the agent has the tendency to distribute his consumption over the time, we assume that the agent's intertemporal preferences are given such that:

$$H_{opt} = \left\{ h_{opt}(0), \dots, h_{opt}(t_b), \dots, h_{opt}(s) \dots, h_{opt}(T) \;\middle|\; \begin{matrix} 0 < h_{opt}(t_b) < h_{max} \\ \wedge \\ 0 < h_{opt}(s) < h_{max} \end{matrix} \right\}. \tag{16}$$

This implies that if $h_{opt}(t) = h_{max}\ \forall\, t \in [0, t_b - 1]$, then $h_{opt}(t_b) < R(t_b)$ must be true in order to have $0 < h_{opt}(s) < h_{max}$. So, considering the implications of (15) and (16) and lemma 1, it is possible to assert the following:

Lemma 2: Given the condition (15) and (16), and given two possible strategies that can be derived by the decision making process of the agent, the first one, $H_{opt} = \{h_{opt}(0), \dots, h_{opt}(t_b), \dots, h_{opt}(T)\}$, in which, at time t_b, $\frac{\delta_{t_b}}{\delta_{t_b+1}} = \frac{\delta_{t_b+1}}{\delta_{t_b+2}}$, and the second one, $H_{bias} = \{h_{bias}(0), \dots, h_{bias}(t_b), \dots, h_{bias}(T)\}$, in which, at time t_b, $\frac{\delta_{t_b}}{\delta_{t_b+1}} > \frac{\delta_{t_b+1}}{\delta_{t_b+2}}$, then in the time interval $[0,T]$, there exists at least one period, t_b, such that $h_{bias}(t_b) > h_{opt}(t_b)$.

In fact, R_0 is unique and invariable with respect to the strategy implemented. The (15) implies that there exists at least one period where $h_{bias}(t) < h_{max}$ and at least one period where $h_{opt}(t) < h_{max}$. Given the existence of a first period in which $h_{opt}(t)$ is lower than h_{max}, t_b, if $h_{opt}(t_b) < h_{max}$ and $h_{bias}(t_b)=h_{max}$, clearly $h_{bias}(t_b) > h_{opt}(t_b)$. Additionally, in the case in which $h_{opt}(t_b) < \mathrm{h}_{\mathrm{max}}$ and $h_{bias}(t_b)<h_{max}$, because in this first period, it is clear that $R(t_b)$ has the same value in both strategies, and because $R(t_b)$ must be greater than $h_{opt}(t_b)$, in consequence of (16), taking care of the lemma 1, the present bias as expressed in (12) determines that $h_{bias}(t_b) > h_{opt}(t_b)$.

The lemmas just enounced have deep consequences in relation to the outcome of cooperative behavior implemented by an agent inside a group of harvesters managing a common stock of resources. In fact, the same relationship expressed in these propositions also exists when an agent inside a group has cooperative behavior.

In fact, two possible outcomes of the process of maximization also exist in the case of cooperative intentions of the agent: one derived using an exponential discount rate and the other derived by present bias behavior. Both the outcomes correspond to a cooperative strategy, but in the first case it is a no-bias cooperative strategy (from now named "optimal strategy"), and in the second case it is a biased cooperative strategy (from now named "biased strategy").

The context in which the agents cooperate in the management of the commons are so defined: the number of the harvester, N, is common knowledge and homogeneity is assumed between the N agents in the instantaneous harvesting utilities $u_n(h_t)$ with $0 \leq h_t \leq h_{max}, \forall\, n \in N$.[8] Recall that the agent does not exercise a deliberative choice of one or the other strategies, but can choose between cooperating and being a free-rider (or stop cooperating). It is not possible for a biased agent to implement the optimal

[8] In the following, heterogeneity will be assumed in the bias factor.

strategy; this is a consequence of the naïve nature of a biased agent who is not conscious about the implementation of a biased strategy.[9]

Therefore, for the single cooperative agent, when he choices to cooperate, the optimal solution is given by the maximization of the sum of the utility of the *N* agents:[10]

$$\max_{h_i} \sum_{i=1}^{N} U_i \quad \text{where} \quad U_i = \sum_{t=0}^{T} \delta_i(t)\, u\big(h_i(t)\big), \tag{17}$$

under the constraints and conditions that we have expressed earlier.

Under the hypothesis of absence of present-bias,[11] the cooperative harvesting plan is the optimal cooperative strategy:

$$H_{opt}^{c} = \{h_{opt}^{c}(0), \ldots, h_{opt}^{c}(t), \ldots, h_{opt}^{c}(T)\}. \tag{18}$$

It easy to understand that a lower amount left unharvested, with respect to the prediction of the optimal cooperative strategy, is also the observable effect of a potential act of free-riding. In particular, free-riding behavior at a given time *t* could emerge when the agent harvests an amount greater than the optimal cooperative one:

$$h_f(t) > h_{opt}^{c}(t). \tag{19}$$

Proceeding with the no biased behavior, it is understood that a biased cooperative agent maximizes the total amount harvested by the group of *N* agents as expressed in (17) when his utility function is:

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[9] It is recalled that in this model it is assumed naïveté for the biased agents, such that naïve agents are fully unaware of their intertemporal inconsistency and of their future re-evaluation of the harvesting amounts.

[10] It is assumed there is homogeneity in the utility function, and consequently the cooperative agent maximizes the sum of the utilities.

[11] The hypothesis is satisfied when $\frac{\delta_t}{\delta_{t+n}} = \frac{\delta_s}{\delta_{s+n}}\ \forall\, t \in [0,T]\ \wedge\ \forall\, s \in [0,T]$.

$$U_i = \sum_{t=0}^{T} \delta_{bias}(t)\, u(h_i(t)), \tag{20}$$

where δ_{bias} has the properties expressed in (12), will have the biased cooperative strategy:

$$H_{bias}^c = \{h_{bias}^c(0), \ldots, h_{bias}^c(t_b), \ldots, h_{bias}^c(T)\}. \tag{21}$$

Now, considering the results described in lemmas 1 and 2, given that (15) and (16) hold, it is possible assert the following:

Proposition 1: Given two possible outcomes of the optimal solution in presence of cooperative intentions of the agent, the optimal no-bias

$H_{opt}^c = \{h_{opt}^c(0), \ldots, h_{opt}^c(t), \ldots, h_{opt}^c(T)\}$, in which $\frac{\delta_t}{\delta_{t+1}} = \frac{\delta_s}{\delta_{s+1}}\ \forall\, t$, and the bias $H_{bias}^c = \{h_{bias}^c(0), \ldots, h_{bias}^c(t_b), \ldots, h_{bias}^c(T)\}$, in which

$\frac{\delta_t}{\delta_{t+1}} > \frac{\delta_s}{\delta_{s+1}}$ for $t = 0$ and $\frac{\delta_t}{\delta_{t+1}} \geq \frac{\delta_s}{\delta_{s+1}}$ for $t > 0$, with $t < s$ and $t, s \in [0, T]$, exist at least a time t_b in $[0, T]$ such that:

$$h_{bias}^c(t_b) > h_{opt}^c(t_b). \tag{22}$$

So, if several reasons could lead the agents to defect by a perfect cooperative strategy, also a pure cooperative agent can implement a strategy that does not coincide with H^c_{opt} even when his aim is 'cooperate' because his choices can be affected by limited capabilities in using a constant discount rate, as in the case of present-bias. In what follows, the manner in which the effect of the present-bias, also in the presence of cooperative intentions, can trigger dynamics of defections is exposed.

4. Cooperation failure due present-bias

In a situation in which (22) holds, if the agents cannot be sure about the biased nature of the choices of others, it is not possible for a member of the group to distinguish if another member of the group harvests an amount greater that the optimal cooperative because he has free-riding intentions or because it is a cooperative biased action. Therefore, an excessive harvesting of some present-biased agent can be erroneously interpreted as an act of free-riding, and in a tit-for-tat strategy can trigger a round of defections.

In order to demonstrate this assertion, a situation in which there are only two harvesters is considered and they are conditional cooperators that play a tit-for-tat strategy. They harvest simultaneously from the same stock of resources. It is possible to assign to one agent the capability to suppose that the other agent can be biased, but have no information about cooperative intentions of the other or about the biased discount factor, so the agent lacks any ability to distinguish the biased agents from the free-riders.[12] The agents are homogeneous in the instantaneous harvesting utilities, $u_i(h_t) = u_j(h_t)$, but heterogeneity is assumed in the myopic discount factor $\delta_{bias}(t)$ as defined in (12), hence, denoting i and j as the agents, where the agent i has stronger present biased preferences, then:

$$\left.\frac{\delta_i^b(t)}{\delta_i^b(t+1)}\right/\frac{\delta_i^b(s)}{\delta_i^b(s+1)} > \left.\frac{\delta_j^b(t)}{\delta_j^b(t+1)}\right/\frac{\delta_j^b(s)}{\delta_j^b(s+1)} \quad \text{with } s > t \text{ at least for } t=0 \tag{23}$$

in a situation in which in the hypothetical case of no bias is $\frac{\delta_i^{opt}(t)}{\delta_i^{opt}(t+1)} = \frac{\delta_j^{opt}(t)}{\delta_j^{opt}(t+1)}$. Now,

[12] Here the existence of the possibility that one of the two agents can be not biased is assumed.

considering (23), because the instantaneous harvesting utilities are $u_i(h_t) = u_j(h_t)$, with $0 \leq h_t < h_{max}$, that (15) guarantees the existence of a t_b such that $h_j(t_b) < h_{max}$, and considering the results exposed in proposition 1, then:

$$h_i^b(t_b) > h_j(t_b), \tag{24}$$

where $h^b_i(t_b)$ and $h_j(t_b)$ are the amounts effectively harvested by the agents given the management strategies when behaviors are biased, at least for the agent i, and coincide with the cooperative amounts $h^c_i(t)$ and $h^c_j(t)$ as expressed in (21), then:

$$h_{opt}^c(t) \leq h_j(t_b) < h_i^b(t_b). \tag{25}$$

Because the agent j does not have instruments in order to distinguish if the higher harvesting of the other agent responds to a cooperative biased strategy or to free-riding intentions as expressed in (19), the agent can be induced to opt for a trigger strategy in the presence of $h_i(t)>h^c_j(t)$ when it responds to a cooperative strategy, such as in $h^b_i(t)=h^c_i(t)$. If agent j interprets $h^b_i(t_b)$ as a free-rider attempt, the trigger strategy of agent j may involve an increase in the next harvesting level until the Nash dominant non-cooperative amount $h_j(t_b+1)=h_{max}$, while agent i still harvests his own cooperative amount such that, if $h_i(t_b+1) < h_{max}$ at time t_b+1 is:

$$h_i^b(t_b + 1) < h_j(t_b + 1) \text{ with } h_j(t_b + 1) = h_{max}. \tag{26}$$

The increase in the harvesting level of agent j cannot be interpreted by agent i as an answer to his biased behavior because – as this model assumes – naïve agents are not conscious of their bias and are unable to recognize the appearance of their behavior as potential free-rider behavior. In fact, naïve agents have incomplete self-knowledge regarding the biased nature of their own behaviors.

Hence, observing an amount harvested by agent j greater than the cooperative amount, agent i can interpret the harvesting amount of the j agent as a free-riding behavior attempt. It is not motivated from the viewpoint of agent i because he himself has only cooperated until time t+1; consequently, he also can choose to start a trigger strategy harvesting at time t+2 an amount equal to h_{max}. At this time a non-cooperant Nash equilibrium is reached in which:

$$h_i(t+2) = h_j(t+2) = h_{max}. \tag{27}$$

Similar dynamics can also be triggered with a large number of harvesters. So, the question that is raised next is how the implication of present-bias in these defective behaviors from the cooperative equilibrium can explicate a dynamic of cascading defections.

5. A restrictive case of cascading defections

Because the issue is how the present-bias leads towards defective strategies in the absence of which such strategies will not occur, it is not necessary to analyze the behavior of the agents that deliberately choice to be free-riders from the beginning. In this case, any effect of present-bias is not relevant to adopting defective strategies for the obvious reason that in presence of free-rider intentions, the defective strategies from the cooperative equilibrium are a consequence of free-riding itself a priori with respect to the intertemporal bias. Hence, to show the effect of the present bias in the trigger a defective strategy it is considered the case in which all the N agents are cooperative.

The agents simultaneously harvest from the same stock of resources for T periods, the features regarding the stock of resources, growth rate, constraints and utility function are those used until now and, therefore, it is not necessary to repeat them. Agents follow a tit-for-tat strategy, implying that they choose the cooperative strategy in the first round, but their cooperative intentions are not common knowledge. Agents are heterogeneous in their bias discount factors, and each agent makes his choice of harvesting for a given period after having observed the amount harvested by the other agents in the period before, which is the only information about others made available.

In every period t each agent can do a cardinal order of all the amounts harvested, such that it is identifies with $h_1(t)$, the amount harvested by the agent that harvests less, and in an increasing order A_h until $h_N(t)$, where agent N is the one who harvests more:

$$A_h = \{h_1(t), \ldots, h_n(t), \ldots, h_N(t)\}, \tag{28}$$

where each n agent can distinguish the n-1 agents that have harvested less than him from the N-n agents that have harvested more.

At every round each agent decides whether to implement the cooperative or defective strategy. In the first case, the cooperative amount harvested will be given by the maximization at time t of (17), under the usual constraints, for the periods of the residual lifetime $[t, T]$. Otherwise, the defection strategy consists of the adoption of the dominant Nash strategy that implies harvesting h_{max} until the end of the interactions.

Each agent assigns a given probability, $p_n(f)$, that other agents are free-riders; $p_n(f)$ is based only upon the agent's personal belief, such the same probability to be a free-rider is assigned to each other agent, so:

$$p_n(f) = \frac{F_n}{N-1}, \tag{29}$$

where F_n is the number of free-riders present in the group estimated by the agent n.

The estimation is only subjective and is formulated by the agent in a condition of lack of information, and thus it is not assumed that this estimation is equal for all the agents.[13] The agent constructs his personal beliefs with an action of mental accounting where he infers the probability used in the actual context from his past experiences in other contexts (Gigerenzer et al., 1991). The logical induction derived from the

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[13] The estimation occurs in a context where each agent is subjected to the complete lack of information regarding the real intentions of others; hence, the estimated presence of a free-rider is not related to the real presence.

representative agent's subjective long-term memory suggests that, because he experienced acts of free-riding in similar contexts, he should utilize his past experiences in the present context, assuming a strictly positive probability that other agents could be free-riders. Hence, we have that:

$$p_n(f) > 0 \;\; \forall\, n \in N. \tag{30}$$

The representative agent starts harvesting a cooperative amount, $h^c{}_n(t)$, continuing to act cooperatively as long as he believes that the other agents are also cooperating. The strategy instead prescribes the defection when the agent's belief leads him to estimate that at least one agent with free-rider intentions has caused him damage with an amount harvested that is greater than the cooperative amount $h^c{}_n(t)$. Hence, the condition of damaging harvesting occurs at time s when a member of the group takes an amount greater than the cooperative one of the agent n:

$$h_j(s) > h_n^c(s) \;\text{ with }\; j \in N. \tag{31}$$

In the case in which the damage occurs because of free-riding, the agent defects. So, at each period t the agent n observes the harvesting order, and at time t+1 he will select the defective strategy when he has observed the damage occurs, and there is a given probability that among the agents who create the damage there is at least one free-rider. This probability, $P_n(F \geq 1)$, to determine a defective choice, needs to be a value at least big enough for the agent to evaluate it as sufficient to the defect: $P_n^d(F \geq 1)$.

Therefore, assuming that s is a period within $[0,T]$ in which (31) holds, the agent defects after time s when the following takes place:

$$P_n(F \geq 1)_s \geq P_n^d(F \geq 1), \tag{32}$$

where $P_n(F \geq 1)_s$ is the probability condition estimated at time s. Hence, the harvesting strategy of agent n will be as follows:

$$h_n(t) = \begin{cases} h_{max}, & t > s \text{ if } P_n(F \geq 1)_s \geq P_n^d(F \geq 1) \wedge h_j(s) > h_n^c(s), \\ h_n^c(t), & \text{otherwise.} \end{cases} \quad (33)$$

The result of the first proposition expressed in (22) and the condition (24) determined by the heterogeneity in the bias factor imply that there exists a first period in $[0,T]$ in which (31) holds such that the agent n is posed in a condition of damage. The observations of the amounts harvested enable the agent to circumscribe the N-n agents that determine damage. Among these, the agent n evaluates the presence of the free-riders in order to verify the realization of condition (32). Therefore, defining

$$\Omega = \{1, \ldots, n, \ldots, N | 1, \ldots, N = f, c\} \quad (34)$$

as the set of all the possible compositions of the group on N agents where each agent can be a free-rider, f, or a cooperant, c. The number of the possible cases can be given by the ordered selections of N-n subjects in Ω, with the exclusion of the agent himself, $\binom{N-1}{N-n}$.

The probability that there is a situation, where among the N-n agents there is at least one free-rider, is given by the ratio between the favorable cases and the possible ones. The favorable cases are those where in the N-n agents of the upper sub-group, the number of potential free-riders are between 1 and F_n. The probability of presence of a given number of free-rider, q, inside subgroup N-n is defined as:

$$P(F = q) = \frac{\frac{F_n!}{q!(F_n - q)!} \frac{(N-1-F_n)!}{(N-n-q)!(n+q-1-F_n)!}}{\frac{(N-1)!}{(N-n)!(n-1)!}}, \quad (35)$$

where the probability for each agent that f is true, about the event (f,c), is given by the subjective estimation of the agent n, $p_n(f)$, as derived by (29).

Therefore, we have:

$$P_n(F \geq 1) = \sum_{q=1}^{F_n} P(F = q), \quad (36)$$

where F is the number of free-riders.

The defection choice that is derived from (33), given a period s in $[0,T]$ in which the condition (31) is verified a first time, occurs if the probability of the presence of at least one free-rider $P_n(F\geq 1)$ is greater than or equal to $P^d{}_n(F\geq 1)$. Now, considering the value of $P^d{}_n(F\geq 1)$, it is assumed that for a probability of the presence of at least one free-rider between the N-n agent that harvests more, close to the certitude that is $P_n(F \geq 1) \approx 1$, each agent n chooses the non-cooperative harvesting; hence, having $P_n^d(F \geq 1) \leq 1 \;\; \forall \;\; n \in N$, it will be:

$$h_n(t) = h_{max} \text{ when } P_n(F \geq 1) \approx 1 \;\; \forall \;\; n \in N \tag{37}$$

Now, consider an order that includes all N agents, where each n agent has the position equal to the position that his harvesting h_n has in the order defined in (28). This gives a cardinal order that identifies with n=1 the agent who has harvested less and, therefore, increasingly until agent N has harvested more than all the others; hence,

$$A = \{1, \ldots, n, \ldots, N\}. \tag{38}$$

Each agent estimates a probability of the presence of a free-rider among the N-n agents that have harvested more than he, $P_n(F\geq 1)$, as defined in (36).

It thus becomes easy to understand that, for an n that approaches 1 in the order defined in (38), remembering that $P(\mathrm{F}=q)=0$ when $n < F_n+1-q$, we have $P_n(F \geq 1) \approx 1$. This implies that at least the agent that has the first place, n=1, in the order A at time s, will decide to defect starting in period s+1. In this way, a new order A is generated at time s+1 in which a new agent takes the first position.

Keeping in mind (37), at each period t, after it is verified for the first time the condition in (31), $t > s$, at least one agent chooses a defective harvesting amount that is equal to h_{max} from t+1 until T. In fact, at every time t+1 the defection of an agent that, at time t was in the condition $P_n(F \geq 1)_t \geq P_n^d(F \geq 1)$, determines a new order where at least one agent, that at time t+1 had harvested the cooperative amount $h_c(t+1)$, evaluates a $P_n(F \geq 1)_{t+1}$ sufficient for the defection at time t+2. This is because at every period there is a new agent n in the first place in the order A such that $P_n(F \geq 1) \approx 1$; hence (32) holds true. Therefore, in the following period he will switch from the cooperative strategy to the defective one; so, it is possible to assert the following:

Proposition 2: When agents adopt the strategy defined in (33), with heterogeneity in the present-bias factor as defined in (12), and they assign a positive probability of the presence of free-riders inside the group as in (30), and it is assumed that for every agent a probability of the presence of at least one free-rider between the *N-n* agents that harvest more is close to 1, $P_n(F \geq 1) \approx 1$, makes that (32) holds, and considering that there exists at least one period s in $[0,T]$ such that the condition in (31) is verified, then for every period after time s at least one agent inside the group stops to cooperate.

The process just exposed auto-fuels time after time and leads, for a sufficiently large time of interaction T, to the disappearance of the cooperative actions within the group reaching a non-cooperative equilibrium in which all the agent harvest h_{max} despite their previous intentions of cooperation. This process is trigged by the presence of present-biased preferences.

6. Extensive cases: condition for a cascade of defections

This work has showed that within a context populated by conditional cooperators with heterogeneous myopic discount factors, the present-biased preferences can lead to the application of a triggered strategy that directs the community to excessively increase their harvesting level, even if their motivations were cooperative. With the restrictive case, this work has revealed the occurrence of cascading defections, assuming blindness and no-awareness of the bias of others and absence of tolerance for the presence of free-riders.[14] Furthermore it has considered the dominant Nash strategy as the only defective strategy implementable. But, conditions that are wider and less restrictive will be defined next. Specifically, the conditions regarding the two decisive decision-making elements of the defection will be defined: first, the critical level of estimated free-riders inside the group, implying that over a given number of supposed free-riders that damage the agent, she will not be available to cooperate any further, and consequently the defection starts when the estimated probability of the number of free-riders that exceed the critical level is considered sufficiently high by the agent in order to defect – and, second, the definition of the behavioral strategy adopted.

6.1 Condition regarding the critical value to defect

Only on rare occasions do agents behave under certainty; in the restrictive case the implementation of a defection strategy occurred for a probability of the presence of free-riders close to certitude, which it is too restrictive to fit well with reality. However, we can easily assume that the agent can choose to stop to cooperate in absence of certitude as well, without any change in the conclusion drawn in the cascade of defections mentioned earlier. In fact, for having at least one agent that stops to cooperate at every period is sufficient to assume that the probability $P_n^d(F \geq 1)$ must be positive:[15]

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[14] $P_n^d(F \geq 1)$ accurately expresses this absence of tolerance because it expresses that the presence of just one free-rider (or the belief that there is a free-rider also because of an erroneous evaluation) is sufficient to trigger the defection.

[15] It is trivial that if the defection occurs for a probability of the presence of a free-rider lower that one, the result is the same as obtained when the defection begins just in presence to the certitude.

$$0 < P_n^d(F \geq 1) \leq 1 \quad \forall\ n \in N. \tag{39}$$

Furthermore, it could be assumed that the agent can consider an estimated presence of only one free-rider inadequate to start a trigger strategy, but he may choose to defect for more than one estimated free-rider. In this case, agent n is willing to accept the presence of a physiological number of free-riders, q_n, inside the group.

We can also extend the nature of this physiological number of free-riders to include those who erroneously behave as free-riders. This implies that the agent accepts the presence of a given number of agents within his group of harvesting who behave in a manner compatible with free-rider intentions. This extension opens up the opportunity of introducing heterogeneity within the model, in particular, making it possible to have both pure naïve agents and agents that are conscious of the possibility of an erroneous implementation of a free-riding harvested amount. For naïve agents, q_n represents merely the acceptable number of free-riders within the group, whereas for the second one it represents the acceptable number of individuals that behave like a free-rider, that includes even those who erroneously act as free-riders.[16] A sufficiently large probability that the estimated number of free-riders is greater that q_n will induce the agent to defect.

Hence, $P_n(F>q_n)$ is defined as the probability - estimated by the agent n – of presence of more free-riders than the physiological one, among the N-n agents who, with their higher harvesting, cause to agent n harm; such that:

$$P_n(F > q_n) = \sum_{q=q_n+1}^{F_n} P(F = q). \tag{40}$$

The conditions necessary for the defective choice are as follows:

[16] For the simplicity of narration, for both kinds of agents, q_n refers to the physiological number of free-riders within the group (without specifying the peculiarity of the case of the no-full naïve agents).

$$P_n(F > q_n)_s \geq P_n^d(F > q_n) \text{ with } q_n < F_n, \tag{41}$$

where $P_n(F > q_n)_s$ is the probability evaluated at time s in $[0,T]$ such that the agent stops cooperating when at time s the condition in (31) is verified, and the estimated number of agents that harvest a compatible free-rider amount exceeding the physiological one for a sufficiently large probability of at least $P_n^d(F > q_n)$, where:

$$0 < P_n^d(F \geq q_n) \leq 1 \qquad \forall\ n \in N. \tag{42}$$

The only condition over q_n is that it must be lower than F_n, that is the conditio sine qua non to have a conditional cooperant. In fact, if hypothetically the agent takes the non-cooperative amount only if the number of evaluated free-riders is greater than F_n, it means that he is willing to defect for an evaluated presence of free-riders between the N-n agents that cause him damage greater than the number that he has assumed to be present in the group of N agents, but this is not a real possibility of defecting. In this case the behavior is the behavior of an unconditional cooperant, that a priori and independently by other elements, always chooses the cooperative amount.

Now, continuing to refer to the strategy defined in (33), but where the condition for harvesting h_{max} at time $t > s$ is $P_n(F \geq q_n)_s \geq P_n^d(F \geq q_n) \wedge h_j(s) > h_n^c(s)$, in others cases the agent cooperates,[17] assuming the condition expressed in (41) and (42), it is evident that when we assume $q_n \geq 0$, given the cardinal order defined in (38), for n that approaches to 1 in the (40), we have:

$$\overrightarrow{\lim_{n \to 1}} P_n(F > q_n) = 1. \tag{43}$$

[17]The set of strategies that leads to cascading defections is wider and does not require the strict adoption of the Nash dominant harvesting, as will be shown in the following.

So also extending the properties of the agent's behavior to the condition (41) and (42), at least one agent in each period is in the condition to defect because given the result obtained in proposition 1 that guarantees the existence of a time s in $[0,T]$ such that $h_j(s) > h_n^c(s)$, and given that $0 < P_n^d(F \geq q_n) \leq 1 \ \forall \ n \in (1, N)$, the result in (43) ensures that the condition in (41) is verified. Therefore, it is possible assert:

Lemma 3: If each agent assigns a positive $p_n(f)$ for every other agent, and for each agent the probability of an excessive number of free-riders that implies the defection is $0 < P^d{}_n(F>q_n) \leq 1$ with $q_n < F_n$, then for every period after time s at least one agent inside the group will stop to cooperate.

This leads to a decrease in the cooperative behaviors with the passing of the interactions, and this decrease depends not on the real presence of an excessive number of free-riders but on the impossibility to distinguish the free-rider attempts from the cooperative but present-bias choices.

6.2 Conditions for the harvesting strategy

Until now, the only strategy set considered was one that prescribes, as a defective choice, the non-cooperative dominant strategy, $h_n(t)=h_{max}$; but, it is possible to consider a wider range of defective strategies. It will be shown that when an agent adopts a tit-for-tat strategy, it is possible it will result in a cascade of defections, especially if the defective choice is different from the non-cooperative dominant ones. In fact, it is sufficient to consider the adoption of a strategy that prescribes, that when the conditions given by (31) and (41) occur, the agent increases his harvesting of an amount arbitrarily greater than those of the precedent period and, that the new amount also guarantees a harvesting greater than the cooperative amount. If after the increase, the defective conditions no longer hold true, the agent maintains a harvesting amount not lower than the previous one, $h_n(t\text{-}1)$, provided that this amount is greater that the cooperative one for period t, in order to maintain the non-cooperative behavior. Otherwise, he will harvest an amount arbitrarily greater than the cooperative one, to maintain the decision to stop cooperating after the defection conditions are verified the first time; and, the increase in the harvesting occurs each time that the defective conditions are verified in order to avoid the permanence of the damaging situation. In this case,

$$h_n(t) = \begin{cases} h_n^c(t) & t \le s_m \\ h_n(t-1) + \epsilon_n(t) & t > s_m \vee t = s+1 \text{ if } h_n(t-1) > h_n^c(t) \\ max\{h_n^c(t) + \epsilon_n(t), h_n(t-1)\} & \text{otherwise} \end{cases} \quad (44)$$

$$\text{with } \ t \in [0,T], \qquad s_m = min(S_n), \qquad s \in S_n \subseteq [0,T],$$

where S_n is the set of all the periods s in $[0,T]$ such that the condition (31) and (41) are simultaneously verified. Furthermore, the arbitrary increase must be a strictly positive amount just sufficient to have $h_n(t) > h_n^c(t)$ and $h_n(t) > h_n(t-1)$, defined as:

$$\epsilon_n(t) = f\big(t, h_n(t)\big) > 0 : \ h_n(t) > h_n^c(t) \ \wedge h_n(t) > h_n(t-1). \quad (45)$$

As shown earlier in proposition 1, there exists at least a time t_b in $[0,T]$ such that $h_n(t_b) > h_n^c(t_b)$ when the agent has cooperative but biased preferences, and t_b is defined as the first period in which, because of the heterogeneity in the bias discount factor, given the implication of (23), $h_j(t_b) > h_n^c(t_b)$ with $j \neq n$; and at time t_b at least one agent is in the position to defect in the next round, as shown in lemma 3, because at time t_b at least for the agent in the first position in the order expressed in (38), the condition in (41) is verified. Hence it is possible to define:

$$\exists\, t_b \subseteq [0,T] \Leftrightarrow A_{t_b}\!: P_n(F > q_n)_{t_b} \ge P_n^d(F > q_n) \ \wedge \ h_j(t_b) > h_n^c(t_b), \quad (46)$$

where A_{t_b} is the order as in (38) defined at time t_b.

Lemma 3 has already revealed that (46) holds true at least for one agent at each period after time t_b when $P_n(f)>0$, $0<P^d_n(F> q_n)\leq 1$ and $q_n< F_n$. In fact, assuming the strategy set (44), that includes not only the dominant Nash strategies, but all the amounts that respond to a defective intention of the agent, for all the agents within the group of N, and defining an order as in (38), we have that for every order A_t for t in $[t_b, T]$, given (42) and (30), at least for the agent in the first position of the order, the probability of the presence of an excessive number of free-riders approaches certitude. Hence, we obtain that:

$$\forall t \in [t_b, T] \; \exists \; A_t \,|\; \text{for } n \to 1 \;\; lim\, P_n(F > q_n) = 1. \tag{47}$$

It is, therefore, possible to assert the following:

Proposition 3: In every period $t \in [t_b, T]$, at least one agent is under the condition to increase the harvesting amount in the next period t+1, adopting a non-cooperative behavior, that referring to the strategies set defined in (44) implies that:

$$\forall\, t \in [t_b, T] \; \exists \; n \in N : \; t = s\,, s \in S_n.$$

Consequently, if at time t, with $t \in [t_b, T], \exists \; n \in N : \; h_n(t) = h^c_n(t)$, then

$$\exists \; n \in N : \; h_n(t+1) > h_n(t) \;\wedge\; h_n(t+1) > h^c_n(t+1).$$

It is thus very clear that during each period some agent increases his harvesting, moving away from the cooperative behavior. This implies a tendency over time to change the order of the agents derived from their harvesting level, with a translation of the already defective agents to a higher position in the order. In this way, the ones who are still cooperative take their place on the lower-side positions observing, time-by-time, the increase in the probability that implies defective choices. This phenomenon determines the increase in the agents that defect by their cooperative behavior over time.

In fact, assuming the condition revealed in the model, it is given a context that for his peculiarities has always at least one agent in the stage of increasing his harvesting over the cooperative level. Therefore, with the passage of interactions, the cooperative agents decrease inducing other agents to defect. Agents defect due to their own lower harvesting and the increase in the value of the probability as expressed in (40) until the level in which the condition expressed in (41) is verified. The consequence of the dynamics exposed is a general progressive increasing of amounts harvested, and a progressive decay of the cooperative behaviors within the group.

7. Conclusion and final remarks

This work has shown that when the agents are conditional cooperators, the present-bias, in the absence of appropriate information or institutions that facilitate the coordination, can trigger a cascade of defections from the cooperative strategy like those observed in the controlled experiments. Moreover, it shows the conditions and dynamics under which the number of individuals that choose to stop to cooperate grows over time.

It is revealed that, if the agents estimate the presence of free-riders within the group of harvesters using their long-term memory, without the information regarding the real number of free-riders, the adoption of defective strategies is generated by the misunderstanding regarding the real intention of the present biased agents and by the restricted self-knowledge regarding their own present biased preferences.

Thus, when agents can behave conformably to their biased preferences, without any instrument of coordination, and sustain their existing desire of cooperation, they direct a suboptimal allocation over time of the amount harvested, damaging themselves and the others.

Therefore, the existence of a cascade of defections, which is also seen in presence of the cooperative and prosocial preferences, can be explicated by the dynamics triggered by present-biased behaviors when the harvesters cannot distinguish the biased choices from the free-rider attempts. In this case the decline in cooperation in the management of commons could be mitigated by adopting instruments designed to oppose the effect of present-bias. It could be possible to qualify the agent's choices, not only as a function of the amount harvested, but also in relation to their social preferences and intentions. Therefore, the drop in cooperative behaviors can also be an effect of the absence of institutional instruments to improve the coordination in the face of the cognitive bias that affects human behaviors.

The model presented responds to the idea that a true representation of human behavior in the social intertemporal dilemma requires the inclusion of the complexity in the decision-making process, in particular, of the cognitive factors that affect the choices. However, it is not possible to ignore the social dimension of human nature when common resources are involved.

In fact, on the one hand, the adoption of sustainable and cooperative behavior in relevant social dilemmas depends on the degree of consciousness regarding the effect of the agents' own behaviors on others, showing interest and care for the common resources. This propensity finds form in the cooperative and other-regarding motives. On the other hand, the choices reflect the capability of a correct evaluation of the costs and benefits that are derived from their own decisions. The intertemporal decision-making process that direct the choices is also the way in which individuals solve social dilemmas. It is within this process that the social preferences find realization. It thus becomes very clear that the cognitive aspects and the behavioral traits of the intertemporal choices, such as present-bias, are fundamental elements that offer a representation of social dilemmas. So the analysis of present biased preferences in the intertemporal dynamic is essential in order to obtain a full understanding of the dynamics of harvesting (and overharvesting) from the commons. This understanding is also necessary to define and create suitable instruments that can sustain cooperative preferences.

The results obtained by this work show with clarity that the cognitive factors that affect the intertemporal ability of the agents are greatly involved in the abandonment of cooperative interaction over time. However, this is a part of the complexity of human decisions, where the causes of a given behavior all interact. Present-bias is one piece of the puzzle that, together with the free-rider opportunities, explicates the phenomena observed. In fact, the rapidity of the cascading defections depends upon several factors. In particular, the presence of heterogeneity in the intentions can contribute to a new complexity of the dynamic. But the presence of free-riders, together with the cooperative present-biased agents, can only be an additional factor in the rapidity of abandonment of cooperative behaviors. Of course, decay in the cooperative intentions can also occur independently from the present-bias if the real free-riders are present in an excessive quantity, per se. Although these elements affect the rapidity and complexity of the defective cascade, but it was not the aim of this work to define this speed. Instead, the claim was to show that the observable and observed decay of the cooperative choices in the common resources dilemmas are not a unique and unequivocal signal of an increase in the free-riding intentions, but can also result from present biased preferences and myopic behaviors of the cooperative agents.

In conclusion, the present biased preferences can lead to the application of a trigger strategy that can direct the community to excessively increase their harvesting level, even if their other-regarding motives were cooperatives. Therefore, a decrease in the cooperative intentions can also be the effect of the absence of coordination instruments in the face of the cognitive bias that affects human behaviors.

These conclusions are relevant and useful for policies whose goal it is to support the cooperative and sustainable behaviors in the management of the common resources. In fact, sustaining the diffusion of the prosocial preferences, if it is an essential prerequisite for the adoption of the cooperation in the commons, cannot offer the results desired if the individuals and the community lack the necessary instruments for wise management of the resources in the face of the risk connected to the present-bias.

In fact, human behavior follows complex dynamic and decision-making processes. The cognitive dimension plays a crucial role and present-bias is one of the elements that, moving far from pure rational behavior, increases the complexity of the human interaction in the commons. For these reasons, further studies should be included on the interrelation between these cognitive intertemporal elements and the social dimension of human nature.

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