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The Evolution of Social Norms in Open-access Resources: an Agent-Based Modelling Approach

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Summary

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1. Introduction

This paper addresses the problem of social cooperation under the influence of a negative externality, known in the literature as "Tragedy of Commons" (G. Hardin 1968).

The simulation is conducted by using agent-based modelling (ABM). The open access good is characterised as a dynamic resource-stock. In this framework, the extraction behaviour of the agents evolves according to payoff opportunities.

In the experiment, when the value of resources is set high enough, and institutional constraints are not able to refrain the harvest of scarce resources, agents have high interests to extract increased levels of the resource, eventually leading to an overuse or more dramatically to a system collapse. In this scenario, the free-rider problem represents a threat to the sustainable low-level harvesting equilibrium. On the other hand, when enforcers are able to refrain the resource overuse of defectors via the imposition of sanctions, higher overall levels of harvests will be observed.

The model is inspired by R. Sethi and E.Somanathan's "The Evolution of Social Norms in Common Property Resource Use" (R. Sethi and E.Somanathan 1996). The method used to conduct this analysis is computer agent-based modelling, which has the ability to model complex systems with a bottom-up approach, where the result of the micro-level interactions between the agents, emerge in a macro-outcome.

The simulation runs over a finite time horizon. The representative agents, fishermen, according to their extraction behaviour will be defined as co-operators, enforcers, or defectors. If the prevailing strategy will be to free ride, a lower aggregate extraction level will be observed or more dramatically, a total depletion of the resource stock might happen. In contrast, if the fishermen will be able to sustain a cooperative behaviour, a higher level of welfare will be achieved in the long-run.

By modelling the resource as a dynamic stock that has a natural growth rate, the evolution of agents's behaviour will be critical with respect to the sustainability of the resource. It will be shown that by sanctioning higher efforts of resource extraction in the short run, higher level of welfare can be achieved in the long term.

The first part will present the theoretical framework of ecological economics and will introduce the topic of the tragedy of commons. In the second part, after having presented a theorical framework of agent-based modelling and its main application, the model will be formally introduced. Finally, in the concluding section of this paper, the simulation will be run in four different scenarios to measure the consequence of agents' behaviours in terms of overall payoff levels.

2. Open access resource management and the Tragedy of Commons

The Common Resource Management dilemma has interested scholars since Machiavelli's times (16th century), who analysed the problem from a political theory perspective (R. Costanza et al. 2014). Nowadays the dilemma is used to address the problem of depletable natural resources' overuse. One of the most common examples of the tragedy of commons is the global climate-regulating system (W. Jager, M.A. Janssen, H.J.M. De Vries, J. De Greef, C.A.J. Vlek 2000). This paper studies the particular case of renewable resources.

In this framework, when natural resources' can be divided into different properties, individually owned, the owners have an incentive to manage the resource stock carefully, so that they will be able to use it in the future. Eventually, problems will arise if the property rights can't be assigned. Without a proper governance system, the resource will be overexploited (E. Ostrom 2006). Several economists have tackled the problem of governing the commons, with different approaches. The awareness of the problem raised when Garrett Hardin published his article titled "The Tragedy of Commons" in 1968 (R. Costanza et al. 2014):

"Even at this late date, cattlemen leasing national land on the western ranges demonstrate no more than an ambivalent understanding, in constantly pressuring federal authorities to increase the head count to the point where overgrazing produces erosion and weed dominance. Likewise, the oceans of the world continue to suffer from the survival of the philosophy of the commons. Maritime nations still respond automatically to the shibboleth of the "freedom of the seas." Professing to believe in the "inexhaustible resources of the oceans," they bring species after species of fish and whales closer to extinction."(G. Hardin 1960)

The assumptions that Hardin made, in analysing the problem, is that harvesters of the open access resource, are rational beings which tend to maximise the resource gain, and their goal is to increase the utility deriving from resource extraction. According to Hardin, the will to increase the profits generating from harvesting more quantity of resource is infinite, while the world, and the resource stock is finite (G. Hardin 1960). Hardin believed that freedom in commons would have ruinous consequences for society because the drive for individuals to maximise their utility from extraction cannot be stopped, and that the participants of the commons are therefore trapped in the dilemma (E. Ostrom 1998).
The tragedy must be prevented with different instruments, i.e. with coercive laws or tax

instruments (G. Hardin 1960).
Elinor Ostrom (2006), the first woman to obtain a Nobel Prize in Economics in 2009, developed the topic of the Tragedy of Commons furthermore and criticised Hardin's work. According to her work "Copying with the Tragedy of Commons", the pessimistic outcome described by Hardin can be escaped, because individuals tend to cooperate to reach a sustainable solution. She developed a set of institutional principles for the management of common-pool resources. Her work suggests the bottom-up governance form to manage open-access resources pool (R. Costanza J. Cumberland, H.Daly, R. Goodland, R.B. Noorgard, I. Kubiszewski 2014).
One way to administrate the appropriations in a common resource pool is to change the payoff rules, by penalising those actors who defect. According to Ostrom et.al 1998, there are several ways to change the payoff structure: the imposition of a fine, loss of appropriation rights, incarceration. The most used, among these, is the imposition of a fine. The implementation of these rules is simple; the difficulties are in the monitoring behaviour, which can be costly (E. Ostrom 1998). Restriction in harvesting is enforced through a total reliance on social norms or through more centralised enforcement mechanisms which imply some form of government. When it is not possible to assign property rights to a common pool resource, the resource is very likely to collapse.

3. Agent Based Modelling

Although the modelling of complex system dynamics will always result in a challenging task, artificial intelligence represents a mighty instrument that might support more integrative analyses. Agent based modelling represents a tool for studying how micro-level characteristics affect the system at a macro level. It is an instrument that can deal with the complexity of the system whilst resulting in a comprehensible outcome. The modelled agents are independent entities that have heterogeneous characteristics and can change their behaviour whilst the experiment is running. Their interaction with the environment and among themselves can be used to analyse quantitatively the complex system[1].
For example, we might want to analyse how a well-known framework responds to different circumstances and want to forecast the result. Alternatively, we may have inadequate knowledge of the framework but, furnished with certain information and comprehension of procedures, wish to examine new theories about the structure and capacity of the system.

[1] W. Jager, M.A. Janssen, H.J.M. De Vries, J. De Greef, C.A.J. Vlek, „Behaviour in commons dilemmas: Homo economicus and Homo psychologicus in an ecological-economic model ".

In this context, ABM represents a powerful tool for economists. Since the disciplines of economics and ecology study the relationship among organisms and environment, and those interactions happen at several levels (i.e. in markets, ecosystems and communities), Agent-based Modelling constitutes a proper tool for the analysis. In fact, starting from micro-level interactions.

According to (S.Heckbert, T. Baynes, A.Reeson 2010, 12):

"They (ABMs) have contributed significantly to ecological theory, including population dynamics, group behaviour and speciation, forestry and fisheries management, conservation planning, and species re-introductions."

4. The Model

4.1 Introduction to the Experiment

The simulation represents a self-governed in-shore fishery. The model is developed in the Netlogo ABM framework (Wilensky 1999) and it presents different types of agents. These include fishermen's agents, which are modelled in three classes of behaviour, and the fishery, that is a set of fish-shaped agents which constitute the harvested resource stock.

The actors behave in response to system conditions. The fishermen, according to their "breed", can have different types of behaviour: they can have a cooperative attitude in order to preserve the resource stock (co-operators), they can free-ride trying to maximize their payoff (defectors), or they can simultaneously harvest at cooperative levels and sanctions the defectors (enforcers). Thus, Hardin's assumptions of fully rational individuals will be partially relaxed.

The different levels of harvest are a result of the effort variable that represents an input of the harvest function. Effort levels are higher for free riders and lower for the cooperative agents. The fishermen agents are represented as ships. Furthermore, Co-operators are identified with the white colour, enforcers with red, defectors with black. The transformation is a consequence of a change in the revenue function, which is directly proportional to the harvest level, and therefore from the available resource stock.
The agents are identified with indexes; these are useful in order to recognise them even after they changed colour due to the "evolution".

The totality of "micro actions" of each agent, which can lead to an externality for the other agents in the environment, lead to an emerging "macro-result".
By varying the parameters set, different scenarios can be observed.

At the end of the simulation, some indicators like catch-to-effort, aggregated payoff and aggregated harvest evaluate the simulation quantitatively. Some variables are "owned" by the agents; these include the payoffs and the harvest. Their value is stored in the agents and, at the end of the experiment it is possible to count the individual values.

In the experiment it is assumed that the number of agents will remain fixed. The number of fishermen is limited with respect to some boundary rules that deny any access to outsiders. According to Ostrom (1998), in in-shore fisheries, boundary rules can be the belonging to a nation or an organisation or to a certain community (E. Ostrom 1998).

Furthermore, in the model it is assumed that the free-rider behaviour can instantaneously be detected by the other agents and sanctioned instantaneously.

In the model, the sanction has immediate effect on the payoffs of the defectors. In reality, the punishment could take several forms. The gear of the defectors could be damaged, or they could receive a fine. The act of punishment is done, and it is costly for the enforcers, because it is assumed that, in approaching the enforcers ship, they face opportunity costs. Being the enforcement act performed by fishermen agents and no guards, it is decentralized.

4.2 The Model

The resource dynamics are modelled through a logistic growth function, which has a replenishment rate *a* and a carrying capacity $K^{\max}$, both exogenously given. The resource natural growth function is given by the following equation:

$$G = a \cdot K \cdot (1 - \frac{K}{K^{\max}})$$

The fishermen agents, depending on "breed" they belong to (extraction behaviour), are equipped with several levels of resource extraction effort, that will be further on denoted by the letter x_i. The minimum viable stock is set at $K^{\min}$ = 20. If the resource stock will fall below this threshold, the experiment will stop running.

At each tick, a new effort variable will be generated for each agent. It represents the labour input. The effort level will stay constant for the whole simulation and it will always be within certain range. Co-operators and enforcers share low level effort x_l, while defectors have a higher effort level x_h. The latter one will be the "utility maximiser effort level", calculated based on value that maximises the payoff function. The former one is the "sustainable effort level" and will result in lower levels of harvest.

The harvest function is a concave function increasing of the current resource stock *K* and positive and concave with respect to the effort level x_i.

$$H = 10 \cdot (x_i - 0.008 x_i^{\,2}) \cdot (\frac{K}{K^{\max}}) \cdot \frac{x_i}{\sum_{i=1}^{n} x_i}$$

The function is increasing for lower values of effort, while, it is decreasing for higher ones. It is directly proportional to the agent *i*'s effort in total effort.

The ratio between K and $K^{\max}$ indicates the effectiveness of the harvest. For high values of K, close to the carrying capacity, the resulting harvest will be more effective, because of the higher number of fishes that are present at the time. The change of the resource $\dot{K}$ stock now can be defined as:

$$\dot{K} = G(K) - \sum_{i=1}^{n} H(x, K)$$

G(K) represents the natural growth rate of the fishery, and $\sum_{i=1}^{n} H(x, K)$ the aggregated harvest (R. Sethi, E. Somanathan 1996). The payoff function of co-operators is the following.

$$\pi_C = p \cdot H(x_l, K) - w \cdot x_l$$

The price *p* and labour cost *w* are exogenously given. The specific payoff function for defectors will take the following form:

$$\pi_D = p \cdot H(x_h, K) - w \cdot x_h - s$$

where *s* stands for sanction. The sanctioning will happen just in the case at the given tick, there will be some enforcers. Costs are shared between the agents that decide to enforce; it is possible to think about a compensation scheme, funded by the enforcers, that allows to share the costs for all participants of the action.

The model designs the enforcers as agents who voluntarily impose the sanctions. However, these can be costly. The costs are directly proportional to the number of defectors and inversely proportional to the number enforcers. The payoff function of enforcers is the following:

$$\pi_E = p \cdot H(x_l, K) - w \cdot x_l - \frac{n_d}{n_e} \cdot c$$

It is easy to see, that, as long no defectors are present, the change in payoff of co-operators and enforcers will be on the same level. In the case of many defectors existing, the enforcers, if costs are positive will have smaller revenues than co-operators. Therefore, the co-operator strategy weakly dominates the enforcer strategy. (R. Sethi, E. Somanathan 1996)

The evolution in behaviour will follow a payoff logic.

$$\dot{s}_{ij} = s_i(\overline{\pi}_i - \overline{\pi}_j)$$

The change of the share *s* of the agent class *i* to the class *j* will be the result of the product of the actual share of agent class *i* times the difference of average payoffs of both classes. This applies for all the classes of agents.

To evaluate the final outcomes, 3 different variables are identified: total harvest, aggregated payoff and catch-to-effort.

Total harvest is the amount of resource stock fished in the experiment. Total payoff collects the sum of agents' individual payoffs and Catch-to-effort is a variable indicates the amount of effort that has been used to harvest one unit of resource.

5 Sensitivity Analysis

5.1 Parameters' choice

The following section gives a brief explanation on the parameters that are used in the four different scenarios.
The starting point fish stock in every scenario is set at K=1000, assuming that, in previous points of time, there was some fishing activities ongoing.

Figure 1 shows the rate of replenishment of the resource stock, a logistic growth function, described in the previous section. The function is concave and the value of the stock that maximizes the function is found at:

$$K = \frac{K^{\max}}{2}$$

Given a carrying capacity $K^{\max}$ = 2000, K=1000 maximizes the natural growth function. Thus, in the beginning of the experiment, the resource will be at its highest regeneration rate.

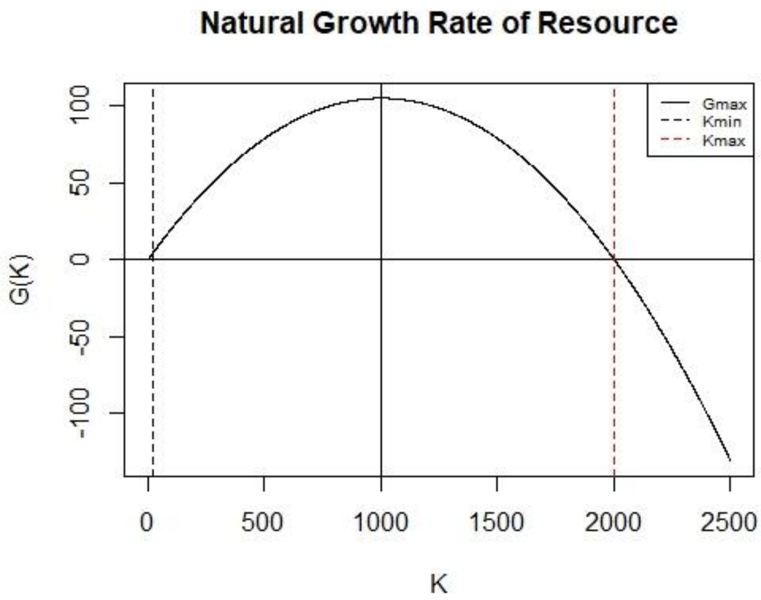

Figure 1: Natural Growth Rate of Resource
Source: prepared by author[2]

[2] The plots were produced via RStudio software.

In an environment without fishermen, the resource stock tends to it carrying capacity, which can be proven to be a stable point. If the initial value of resource is bigger than the minimum viable stock, and lower than the carrying capacity quantity, $K^{\min} < K < K^{\max}$, then G(K)>0. If $K > K^{\max}$, then G(K) < 0, and a negative growth will be observed; again, the system will find its stability point at $K^{\max}$.

If the value of the current resource stock will be close to the carrying capacity or close to zero, a slow growth will be observed.

The replenishment rate is set at *a*=0.21. With the parameter set at this value, the fish stock will be able to regenerate in all scenarios.

Setting this parameter at lower values, when fishermen are present, e.g. at a *a*=0.1, could generate a shock in the system. The resource stock will drop to values below $K^{\min}$ and won't be able to regenerate; in the program, this represents the so-called "tragedy scenario".

The number of total agents is fixed to n=24. We'll assume that at the beginning the agents will choose any of the strategies with equal probability. We'll choose 8 agents of each class. The following graph shows the payoff function of a defector deviating from a co-operator strategy. The rest of the population is composed entirely by co-operators. It shows different values of the current stock and the effort value that maximizes the function, with a set of parameters that will be used later. The vertical dashed lines represent the expected values of effort: in red the lower level of enforcers and co-operators, in black the higher one of the defectors.

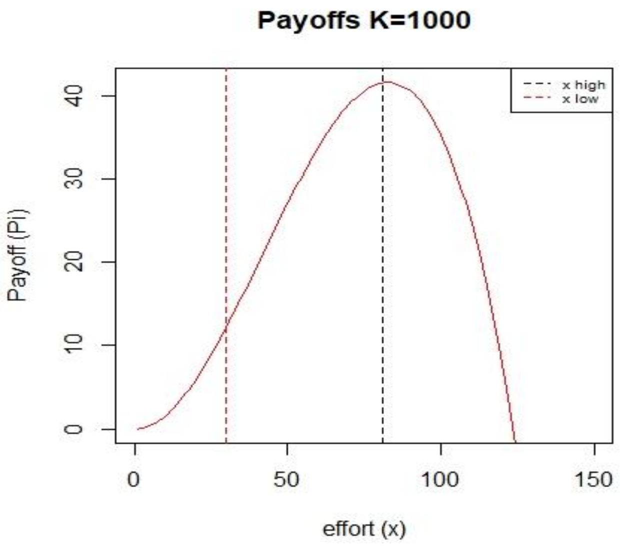

Figure 2: Payoff function K=1000
Source: prepared by author

The value of effort that maximises the payoff function is found at x_h = 83 (black-dashed line in the graph).

This will be the expected effort level of the defectors.

The program in fact, simulates the effort of the defectors randomly, in values of $x_h \in (81;85)$
The expected low effort of co-operators, in values is x_l = 30. Its range is between $x_l \in (29;31)$ chosen arbitrarily below the effort level of the defectors.

The labour costs are set to w=0.025, while the price at p=4. Both parameters are set such that the change in the payoffs will be positive in every possible scenario; in other words, for the fishermen will be always convenient to harvest.

All simulations will have a duration of 200 ticks. The parameters mentioned in this paragraph will remain constant for all the simulations analysed further on.

To show the impact of sanctions and their costs on behavioural equilibria, the next section will present four different scenarios where the sole parameters *s* and *c* (sanctions and costs of sanctions respectively) will be changed.

Table 1 gives an overview on the parameters chosen and the scenarios that will be analysed.

Parameters		Scenario 1 *D Equilibrium*	Scenario 2 *C-E Equilibrium*	Scenario 3 *D-Equilibrium*	Scenario 4 *C-Equilibrium*
Total number of agents	*N*	24	"	"	"
Number of Co-operators	*Nc*	8	"	"	"
Number of Enforcers	*Ne*	8	"	"	"
Number of Defectors	*Nd*	8	"	"	"
Initial Stock	*K*	1000	"	"	"
Replenishment Rate Stock	*a*	0.21	"	"	"
Carrying Capacity	*Kmax*	2000	"	"	"
Labour costs	*w*	0.025	"	"	"
Price	*p*	4	"	"	"
Sanctions	*s*	0	30	30	30
Costs of sanctions	*c*	0	0	1.2	0.6

Table 1: Parameter's overview
Source: prepared by author

5.2 Scenario 1: D-Equilibrium

This scenario is a producer by setting the sanction parameter at *s = 0.*
In this framework, the free riding behaviour is not punished by other fishermen.
Already in the first "tick", due do the great difference in payoffs ($\pi_d(83) - \pi_c(30) \approx 29$), Co-operators and Enforcers will evolve to Defectors. Figure 2 shows the big difference in payoffs in the first round, when K=1000.
Being Co-operators and Enforcers "extinct", the sole class to exist in the long run will be the defectors 'one. But, despite the initial high profits, the system will start to shake.
In fact, after all agents will have become defectors, at levels of stock close to the initial starting point, the aggregated harvest will be higher than the natural regeneration of the resource:

$$\dot{K} = G(K) - \sum_{i=1}^{n} H(x, K)$$

$$\sum_{i=1}^{n} H(x, K) > G(K)$$

$$\dot{K} < 0$$

A negative change of the resource stock will be observed until a steady state will be reached. Consequently, being dependent on the current amount of resource stock, the levels of harvest from the agents will start to drop, starting to adapt to the new quantities.

The Steady State in this system will be found when $\dot{K} = 0$, thus when:

$$\sum_{i=1}^{n} H(x, K) = G(K)$$

The system will find its steady state approximatively after 50 ticks, where the value of aggregated harvest will have equalized the natural growth rate of the fish stock, at:

$$\sum_{i=1}^{n} H(x, K) = G(K) = 95$$

The resulting stable equilibrium quantity of the stock will be found at Ks = 685. Figure 4 shows the values of aggregated harvest and natural growth of resource in function of the actual resource stock, given that all agents have the high effort of the defectors. The vertical dashed line represents Ks = 685. For values of Kmin<K<Ks it will result that G(K) > AH(K). In fact, until the steady state point, the natural growth function of the stock will lie above the aggregated harvest function; in other words, the higher replenishment rate, due to lower values of harvest, will lead to an increase in the resource stock.
Conversely, when Ks < K < Kmax, the aggregated harvest function lies above the growth function, and an involution of the resource stock to Ks can be observed.

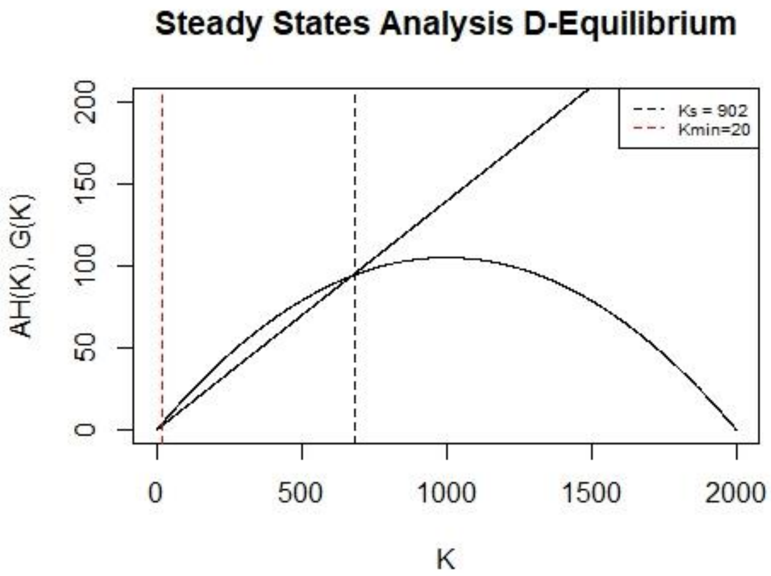

Figure 3: Steady State Analysis – D_Equilibrium
Source: prepared by author

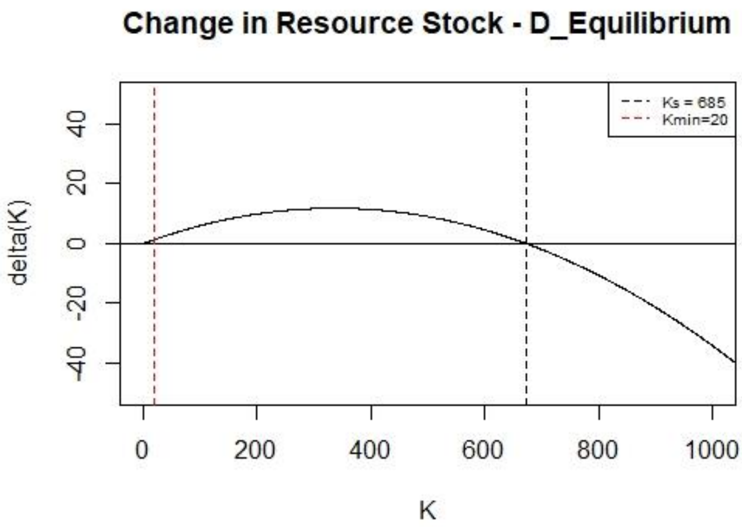

Figure 4: Change in Resource Stock – D-Equilibrium
Source: prepared by author

Figure 4 shows the change of resource stock in the D-Equilibrium, starting with K=1000. Ultimately, the steady state of the systems can be found for K = Ks and at the trivial K=Kmin. The latter case represents the “tragedy-scenario”.

When the parameter of sanctions is set at *s = 0*, defector becomes the dominant strategy. In fact, without being sanctioned, in the short run, defectors will observe higher returns on harvest.

5.3 Scenario 2: C-E Equilibrium

To determine this outcome, a parameter of sanctions *s* will be chosen such that:

$$\pi_c = \pi_e > \pi_d - s$$

The values of *s* that satisfy this condition are found at *s*=30.
Furthermore in this simulation, it is assumed that imposing sanctions is costless: the parameter costs of sanctions *c* are set to zero; this is the reason why co-operators and enforcers have the same payoff.

The *s* parameter value will discourage agents from free-riding.
In fact, cooperative behaviour of agents will lead to a higher yield. In this scenario all agents will evolve into co-operators and enforcers; and all defectors will be extinct in the first tick. Successively, the agents will all evolve in one of the two remaining classes, due to the similar payoffs function. The evolution into one class or the other is aleatory with respect to values of the effort simulation. Figure 5 shows the evolution of the resource stock in the scenario of the C-E Equilibrium.

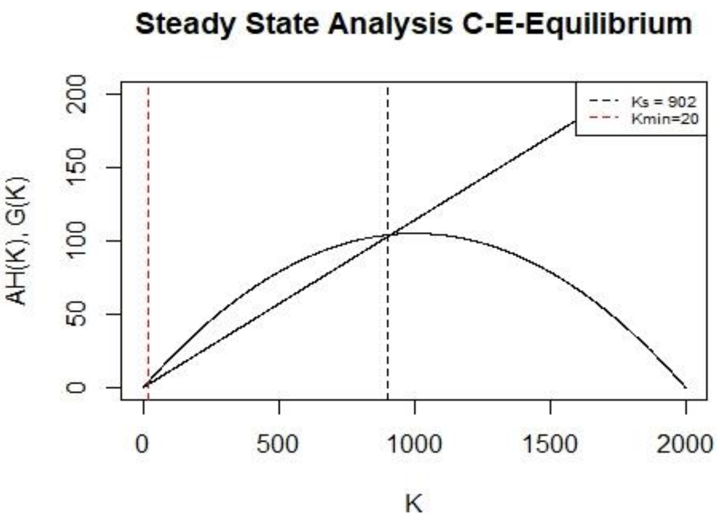

Figure 5: Steady-State Analysis - C-E Equilibrium
Source: prepared by author

For values of K such that K > Kmin, the steady state will be found at Ks = 902. The aggregated harvest function it is now flatter than the one seen in the D-Equilibrium and thus the intercept of both functions will be found at a higher value of resource stock. The equilibrium aggregated harvest quantity and natural growth rate of the stock is now:

$$\sum_{i=1}^{n} H(x, K) = G(K) = 105$$

The conditions of stability of Ks are equivalent the D-Equilibrium's ones and the value of the steady state it is found approximatively after 40 ticks.

5.4 Scenario 3 and 4: D-Equilibrium and C-Equilibrium

The two scenarios show how the high in sanctioning cost, carried exclusively by the enforcers, could influence the final outcome. By setting the parameter value costs of sanctions $c_1 = 0.6$ *and* $c_2 = 1.2$ two very different developments can be observed. The former case will deliver a C-Equilibrium, where solely co-operators will survive and the latter to a D-Equilibrium. The value of the sanction is equal to the previous Scenario.

The spread between co-operators' and enforcers' payoffs in the first ticks, generated through the imposition of the sanction, will lead the enforcers to evolve in co-operators.
In fact, in the 3rd Scenario, being the imposition of a sanction costly, the enforcers will be penalized in terms of short run payoffs, while the co-operators will be not.
Thus, the co-operators strategy will dominate the enforcer one. This will provoke an extinction of the enforcers, and as consequence, the sanction imposed on the free riders, will be nullified. The defectors will observe again higher payoffs, becoming the dominant strategy, and the co-operators will start to evolve to this class.
In the long run, the D-Equilibrium will be stable.

In Scenario 4 the costs of sanction are lower than Scenario 3. The extinction of defectors happens before than the one of enforcers, which tend to evolve towards the enforcers. Being the enforcers penalized in the first rounds of the experiment, in the long run they will change their behaviour to the co-operator one.

5.5 Final Evaluation

Table 2 gives an overview on the quantitative indicators of the different scenarios, produced by one simulation.

"Macro" parameters	**Scenario 1, 3**	**Scenario 2, 4**
Aggregated Harvest	19.550	21.050
Catch-to-effort Ratio	0.05	0.14
Total Payoff	68.164	80.150

Table 2: Quantitative Indicators
Source: prepared by author

Since the change in behaviour happens at the first ticks, the long run results of Scenario 3 and 4, are similar with Scenario 1 and 2 respectively, and can be summarized in the same column.

Scenarios 1 and 3 are characterised by free-riding equilibria, while cooperative strategies dominate the 3rd and the 4th.

By comparing the results on the table, it can be seen that, in presence of resource scarcity, the free riding strategies in the long run deliver lower quantities of total harvest, catch-to-effort ratio and total payoffs.

In this framework, despite the initial higher harvest levels and payoffs of defectors, the contraction of the equilibrium quantity of the resource stock will lead to lower aggregated harvest. Furthermore, the reduction of the equilibrium stock will make the catch-to-effort ratios drop, from values of $\approx$ 0.12 at the first ticks, to values of $\approx$ 0.05 towards the end of the experiment. This ratio implies that, given equal technology assumptions, to yield a marginal quantity of harvest, more input has to be spent. Being the input connected with a cost, it will influence the marginal payoffs of the agents. The macro-outcome of this dynamic can be interpreted through the total payoff indicator.

On the other hand, when cooperative behaviour becomes the dominant strategy the system finds its equilibrium at a higher stock level and, consequently, in the long run, a more effective (catch-to-effort = 0.14) and higher aggregated harvest can be sustained. Due to these conditions, in cooperative equilibria, in the long run the agents will benefit from higher payoffs.

6 Conclusions

Though the simulations, this paper aimed to fill the gap between theory and practice in the topic of open access resources management. The simulation offered insights on resource stock dynamics, as a result of agent's interactions.

Hardin's theory of individuals being utility- maximisers was partially relaxed in order to constitute heterogeneous agents that behave more or less sustainably with respect to the ecosystem.

Based on the assumptions of the model, the simulations have shown that, when the system relies completely on social norms and no monitoring and enforcement is performed, free riding behaviours easily become a dominant strategy and that this type of equilibrium leads to lower levels of welfare. Once defector strategy has become the dominant strategy, it is difficult to recover cooperative equilibria. (R. Sethi, E. Somanathan 1996).

On the other hand, if the community is able to enforce the free riding attitude, higher levels of welfare, without generating an overuse of the resource, can be achieved. But in reality, when enforcement modalities are decentralised, and performed due to voluntary contributions, the free riding problem represents a threat (R. Sethi, E. Somanathan 1996).

Agent based modelling is a powerful tool to explore micro interactions emerging in comprehensive outcomes. However, ABM still presents limits in validation and calibration of models. The output often relies on a simplification of humankind's behaviour, depicted in light of doubtful data sources and requires outstanding programming skills (S.Heckbert, T. Baynes, A.Reeson 2010),

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