Simulation models for economics
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Cooperation vs. Greed

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INTRODUCTION

Our model represents an attempt to investigate the evolution of a group of individuals who face a world of uncertainty and potential dangers for their wealth.

A BIT OF PREVIOUS LITERATURE

This model has been developed having in mind the main studies made in the field of sociology and sociobiology about cooperation between unrelated individuals. The theories of reciprocal altruism, introduced by Trivers (1971), still represent nowadays a mainstream study in order to understand cooperation. According to him, evolution of cooperative behavior can be understood in terms of reciprocal aid giving. Even if aid is costly, individual are willing to bear it if there is a chance of being themselves in the same need for help in the future.
Axelrod demonstrated how effective and powerful were the intuitions of Trivers about cooperation by mean of tournaments, showing how game theory and computer modeling can result as a powerful tool for investigations on the role of individuals in groups and how cooperation can be advantageous under an evolutionary perspective. Tournaments consisted in a repeated (200 iterations) prisoner's dilemma, where a number of strategies were run. Eventually it came out that the most successful strategy was also the simplest one, the so called " tit for tat" strategy. It was first submitted by Anatol Rapoport, a russian mathematician interested in mathematical modeling of social interactions. The “tit for tat” strategy can be resumed as follows: initially an agent chooses to be cooperative, subsequently he will replicate by looking to what the other agent chose in the previous stage of the repeated game. If the other agent was cooperative he will be cooperative too, if the other agent was not, he neither will be cooperative.
Even if reciprocal altruism played a central role in order to explain many social scenarios dealing with cooperation, it has been criticized to rely too much on restrictive conditions; moreover it was not able to give answers to large groups of games with a low chance of being repeated. A contribution to the understanding of how reciprocity works in large cooperative populations of agents was given by Alexander who introduced the concept of **indirect reciprocity**. The difference with respect to previous concepts lays in the fact that indirect reciprocity involves reputation and status; furthermore the return from an aid given to a person in need is expected from someone else than the recipient of aid. Indirect reciprocity has to do with the origins of social norms. Nowak and Sigmund used computer simulations taking into account indirect reciprocity. In this new context any two individuals were required to interact with each other no more than once. Anyway each individual can experience many rounds. Reputation is built on how each individual acted in the previous cycle. If she donated (showing to be “nice”) then she receives a positive score, which contributes to increase her reputation, otherwise score decreases and reputation is consequently affected. Trigger strategies can ensure cooperative equilibrium. In this sense, as Nowak and Sigmund noticed, the step from direct to indirect reciprocity corresponds to the step from personal enforcement to community enforcement.

OUR RESEARCH QUESTION

Up to now we have found out that a large contribution was given by the introduction of agent-based modeling grounded on game theory strategies. Both the common interest in the field of cooperation and the previously mentioned literature led us to ask ourselves what would be the outcome of an experiment where a group of members who behaves in a cooperative effort to grow and defend itself is opposed to another group, which on the contrary is made of selfish individuals, relying on themselves only, in the attempt to survive and increase their wealth.

While most of the literature on cooperation and its evolution within societies is mainly focused on how cooperation arises between individuals, and on how their interactions and strategies work, we would like to propose a different perspective of this topic. That is, starting from a situation where the agents have been previously and exogenously determined as cooperative or selfish, we want to observe how the two groups behave and evolve in a world in which they have to be concerned about their security.

More specifically, we assume an initial population made up of a variable number of agents. To each agent is assigned a distinctive "breed”. In other words, we divide them in equal number but, through a randomized

process, agents can be cooperative or selfish. To each agent is assigned an initial income. The income polarization can be controlled by a slider, so that the experiment can be run under different income distributions.
After this initial and fundamental difference, we will observe two distinct groups of agents, characterized by different aggregate income, depending on initial distribution and the successive randomized assignment of the characteristic breed to each agent. As we previously mentioned the world in which these agents live is characterized by uncertainty about their wealth. In fact a third group of agents populate this world, the stealers, whose unique objective is to subtract, indiscriminately with respect to the breed of the other agents, all their wealth. The initial number of stealers can be decided upon willingness of the executor of the experiment, also in this case by means of a slider, and the initial number will increase by one unit each time a certain threshold of income will be stolen. When stealers increase more than the half of the rest of agents, their reproduction threshold will increase following an exponential function, thus avoiding an over-reproduction. We explain this change in modeling threshold as consequence of stealers obstructing themselves in the space.
At this point a first difference emerge in the behavior of the two "honest" groups of agents. In fact, according to their different nature they will behave differently with respect to the threat represented by the stealers. Indeed, the cooperative ones will choose to guarantee an equal degree of security to each of their components; in order to do so, they tax themselves according with a proportional system. The amount collected through taxation will be used in order to recruit police officers, chosen among the cooperative individuals having a low income profile.
On the other hand, selfish agents will choose to "run alone". That is, regardless of their initial income, they will try to defend themselves with their own resources and will not collect any sort of tax in order to provide to each of the components of their population a minimum defense from stealers. Of course, this choice will lead to imbalanced degrees of security among the component of this agents' breed. In particular we have assumed an initial price for individual security, represented by market price for weapons. This assumption allow us to discriminate between those who can afford this initial expense and those who cannot, separating the world of the selfish agents between the ones who enjoy a certain degree of protection and those who have lower chance in case a stealer agent meet them.
We have also introduced a dynamic effect characterizing the expense for weapons incurred by selfish individuals, the riskier the world becomes (meaning more stealers are present) the higher their expense for weapons to maintain their required security level.
A crucial assumption we make is free-riding: police officers defend everyone, regardless from breed. Actually they decrease the probability of being stolen in a certain diameter. For this reasons the most safe agents would be the rich non-cooperative individuals who enjoy police protection and own also private weapons; then there are all other agents which can be protected if they find themselves sufficiently “close” to a police officer.

At this point, we will face multiple situations for what concern the dynamic of the robbery taking place in our world, due to the fact that we have introduced free-riding and differentiated degrees of protection, depending on variables such as breed of the agents, personal initial income, initial number of stealers.
Furthermore, after this initial setting, in order to provide dynamism and to observe interesting effects on the evolutionary path of these two groups of agents, we have introduced the possibility of investing residual amount of income, saved by each individual, after having incurred in the security expense indifferently whether in the form of a tax or of price for weapons and bodyguards.

However, in some experiments the interest rate applied to investment is not the same for all the agents who saved residual income after the security expense. In fact, in such cases we took into account a positive externality affecting the cooperative agents population : the social capital effect.
According to R. Putman "the central idea of social capital, is that networks and the associated norms of reciprocity have value. They have value for the people who are in them, and they have, at least in some instances, demonstrable externalities, so that there are both public and private faces of social capital". In our framework, we have introduced a positive externality, generated by social capital, in order to highlight the networks and reciprocity put on the table by cooperative agents, in the common effort to stabilize and keep under control the otherwise chaotic situation due to the presence of stealers agents. To remunerate this attitude, we have assigned them a higher return on investment, which can be effectively justified in a realistic context, as an higher capacity to attract investors, since cooperative agents can provide a more stable and, at least on an aggregate perspective, secure investment for a potential and hypothetical external investor.

THE CODE

SET UP:

Main purpose of this section of the code deals with creation of agents and their characteristics. There are three different populations, which are distinguished by "breeds".

breed [stealers stealer]
breed [cops cop]
breed [greedy-citizens greedy-citizen]
breed [friendly-citizens frendly-citizen]

Citizens can be either greedy or friendly. The first one cooperate to protect themselves from stealers: they pay taxes and finance with the revenues a police service (breed "cops", they are themselves friendly citizens chosen on the basis of a low income level). Greedy citizens don't pay for police, but depending from income distribution some of them can afford the price of a weapon (which ensure some degree of protection). All greedy citizens free-ride police services: they enjoy the benefits from having police in the society.

```
to setup
  clear-all
  setup-stealers
  setup-friendly-citizens
  setup-greedy-citizens
  setup-cops
```

Each population owns an "*initial income"* distributed normally among breeds. Friendly citizens pay the tax, then their "*netincome*" is invested and becomes variable "*income*". Rich greedy citizens spend part of their "*initial income"* for buying the weapon, then their "*netincomeg"* is invested too and becomes variable "*incomeg"*. Stealers own their robberies while cops own their wage. Both citizens breeds are stolen with a certain probability, which depends on their distance from policemen and on possession of weapons.

```
friendly-citizens-own [initincome income netincome probstol1 tax investedwage]
greedy-citizens-own [initincome incomeg netincomeg probstol1 probstol2 price]
stealers-own [robbery robberycit robberygreed netincome netincomeg income incomeg]
cops-own [wage initincome netincome income tax treasure]
```

Setting up and defining what each breed owns under an aggregate perspective :

```
  set aggrecit sum [income] of friendly-citizens
  set aggregaterobberycit sum [robberycit] of stealers
  set aggregaterobberygreed sum [robberygreed] of stealers
  set aggregaterobbery sum [robbery] of stealers
  set aggregreedy sum [incomeg] of greedy-citizens
  set aggregatewage sum [wage] of cops
  set collectedtax sum [tax] of friendly-citizens
  set reproduction-threshold intercept-reproduction
```

Now setup each breed :

STEALERS:

Stealers are represented by wolves, we created them with the command "*set-default-shape*". Number of stealers is fixed by a slider, and can therefore freely change among experiment. They all start with an initial

level of robbery equal to zero. They steal to friendly citizens (*robberycit)* , and to greedy citizens *(robberygreed).*

```
to setup-stealers
  set-default-shape stealers "wolf"
  create-stealers number-stealers [set color black setxy random-xcor random-ycor]

  ask stealers
  [set robberycit 0
    set robberygreed 0
    ]
```

FRIENDLY CITIZENS*:*

Friendly citizens are represented by person-shaped agents. Also in this case the number of citizens can be defined on willingness by the executor through a slider. Citizens are positioned randomly and are red-colored. As defined above, each citizen owns an initial income (*initincome*) which is set according to a normal distribution. The executor of the experiment decides the average and standard deviation of initial income through a slider.

```
to setup-friendly-citizens
  set-default-shape friendly-citizens "person"
  create-friendly-citizens number-friendly-citizens [ set color red
    setxy random-xcor random-ycor
     ]
  ask friendly-citizens
  [set initincome random-normal value-mean value-deviation
  set tax trate * initincome
  set netincome (initincome - tax)
  set income netincome
  print initincome ]

end
```

Also tax rate and interest rate can be decided by a slider. Their final incomes are the result of the initial income minus the tax, invested in a “standard” capital market with the formula:
Investment = capital * (1 + i)

GREEDY CITIZENS:

Greedy citizens are blue-colored. They don’t tax themselves in a collective effort to obtain security service. We set a *price* for weapons and net income is set as the difference between *initial income* and the expense for buying the weapon.
Also greedy citizens invest their residual capital, the interest rate they face is called interestgreedy and is set by means of a slider.
The price for the weapon is composed by two elements: an initial cost plus a smaller “renewal” cost they have to pay in every period. Both depend on the number of stealers, according with the intuition that if there is more demand for weapons (because stealer increase), the same should do their price, both are set by means of a slider.
Not every greedy citizen can buy a weapon: if *netincomeg= initincome – price* is greater than zero they will invest this net amount. This means that these citizens had enough income to afford the price of weapons. If, on the contrary, it is lower than zero, they cannot buy it and will therefore invest their original income (*initincome)*.

```
to setup-greedy-citizens
  set-default-shape greedy-citizens "person"
  create-greedy-citizens number-greedy-citizens [ set color blue
```

```
  setxy random-xcor random-ycor
   ]

 ask greedy-citizens
 [set initincome random-normal value-mean value-deviation

 set price  number-stealers * initialcost + number-stealers * marginalcost
 set netincomeg (initincome - price)
 ifelse netincomeg > 0
 [set incomeg netincomeg]
 [set incomeg initincome]
```

COPS:

Finally we set up cops. They come from the breed citizens. In particular we think them as friendly citizens with low income, that can therefore need a job. If their *initialincome* is lower than a certain threshold they change breed and become "cops". They are green colored and randomly distributed in the space. Their *income* is changed into the variable *wage* , which will be based upon the tax collected among citizens. *Treasure* is the booty they get back when are chosen as victims by unaware stealers.

```
to setup-cops
  ask friendly-citizens
  [ifelse initincome <= copthreshold
   [set breed cops
     set color green
     setxy random-xcor random-ycor
     set wage income
     set treasure 0
     ]
   [set breed friendly-citizens]

  ]
```

GO:

After the setup begins the "to go" section of the model. This consists firstly in asking all turtles (independently from their breeds) to move, while assigning to each breed a series of actions which characterize their role in the model. Every turtle moves, citizens (independently from their breed invest and stealers steal. When the aggregate income of either all greedy or friendly citizens goes to zero the model stops.

```
to go
 ask turtles
 [move-turtles]
 ask friendly-citizens
 [invest-cit]
 ask greedy-citizens
 [invest-greedy]
 ask cops
 [invest-cop]
 ask stealers[
  steal
  reproduce]
 update-variables

 if all? greedy-citizens [incomeg = 0] or all? friendly-citizens [income = 0]
```

```
  [stop]

   tick
end

to move-turtles
   right random 360
    forward 1
end
```

Let's look more in detail how each component of the "go" section work. Every individual has a personal income which changes with time. Cops receive with every new tick *wage*, which is the amount of total *collected tax* paid by friendly citizens divided by the number of policemen. Friendly citizens invest at a greater interest rate than greedy citizens but pay also the tax in every period.
Greedy citizens buy too each time some services for guaranteeing a good functioning of their weapons: for instance the wage of their private bodyguards. We generally call all the actions that lead people to earn money "invest".

```
to invest-cop
 set wage wage + collectedtax / count cops

end

to invest-cit
  set income income + income * interestfriendly - (income * interestfriendly) * trate
  set tax (income * interestfriendly) * trate

end

to invest-greedy
  set price count stealers * marginalcost
  ifelse incomeg > 0
  [set incomeg incomeg + incomeg * interestgreedy - (price)]
  [set incomeg 0]
end
```

Stealers act firstly by recognizing who is the citizen/cop they want to attack. It is the farthest one. Victims and robbers recognize themselves. Then with a certain probability the stealer will succeed and take the other's income, but if she met a cop, then her booty will be recovered.
For greedy citizens there are four possible conditions of being attacked in which they could find themselves:
Armed and near a cop = it is the highest protection they can have, probability of thief is 0.3
Unarmed and near a cop = because police protection is more effective than weapons, probability is equal to 0.5
Armed and far from a cop = self-protection leads to a probability equal to 0.7
Unarmed and far from a cop = it is very easy in this condition to steal. Probability equals 0.9

The same reasoning for friendly citizens, with the difference that they cannot have the additional protection of weapons, they face only two probabilities (depending on their distance from cops): 0.9 and 0.5.

```
 to steal
  set victim max-one-of turtles [distance myself]

 ask victim
 [ set farest-stealer max-one-of stealers [distance myself]
   ask farest-stealer

     [if [breed] of myself = greedy-citizens
```

```
[if sum [count cops] of neighbors4 >= 1 and [netincomeg] of myself >= 0
  [ifelse random-float 1.0 <= 0.3
   [set robberygreed robberygreed + [incomeg] of myself
     ask victim
    [set incomeg 0]
    ]
   [set robberygreed robberygreed]]


if sum [count cops] of neighbors4 < 1 and [netincomeg] of myself >= 0

  [ifelse random-float 1.0 <= 0.7
   [set robberygreed robberygreed + [incomeg] of myself
     ask victim
    [set incomeg 0]
    ]
  [set robberygreed robberygreed]]


if sum [count cops] of neighbors4 >= 1 and [netincomeg] of myself < 0

[ifelse random-float 1.0 <= 0.5
  [set robberygreed robberygreed + [incomeg] of myself
    ask victim
    [set incomeg 0]
    ]
  [set robberygreed robberygreed]]


 if sum [count cops] of neighbors4 < 1 and [netincomeg] of myself < 0

[ifelse random-float 1.0 <= 0.9
  [set robberygreed robberygreed + [incomeg] of myself

    ask victim
    [set incomeg 0]
    ]
  [set robberygreed robberygreed]]
]



if [breed] of myself = friendly-citizens

[if sum [count cops] of neighbors4 >= 1

 [ifelse random-float 1.0 <= 0.5
  [set robberycit robberycit + [income] of myself
    ask victim
    [set income 0]]
  [set robberycit robberycit]]

 if sum [count cops] of neighbors4 < 1

  [ifelse random-float 1.0 <= 0.9
```

```
      [set robberycit robberycit + [income] of myself

        ask victim
       [set income 0]
       ]
      [set robberycit robberycit]
      ]]

   if [breed] of myself = cops
  [ ask victim
   [ set treasure treasure + [robberycit] of myself + [robberygreed] of myself
     set wage wage + treasure
     ask farest-stealer
     [set robberycit 0
     set robberygreed 0]]
```

Stealers are the only one that can increase in number. If total amount of robbery is higher than a certain reproduction threshold, stealers are asked to reproduce. Threshold varies with the number of stealers, when they exceed the number of one of the two citizen's breed, it increases exponentially and they have to accumulate a lot of robbery before being able to continue to reproduce.

```
to reproduce

  if robberygreed >= reproduction-threshold or robberycit >= reproduction-threshold
  [  hatch 1
    [lt 45 fd 1]
    ]
end
```

UPDATE AGGREGATE VARIABLES:

Our primary interest is to observe variations in income of the breeds and stealers, trying to compare, *ceteris paribus,* cooperative behavior and taxation, v. individualism and free-riding on public services. Therefore it is fundamental to update variables of interest.
There are aggregate incomes of friendly and greedy citizens, the total amount of collected tax and aggregate amount of robbery stolen to friendly citizens and the aggregate amount fo robbery stolen to greedy citizens; we differentiate between what is stolen to different breeds in order to understand which group is affected more by stealers (*aggregaterobberycit* and *aggregaterobberygreed*).

```
to update-variables

  set aggrecit sum [income] of friendly-citizens  ;; this is the aggregate amount of income owned by
                                                     friendly citizens at each tick
   print aggrecit

  set aggregreedy sum [incomeg] of greedy-citizens ;; this is the aggregate amount of income
                                                       owned by greedy citizens at each tick
  print aggregreedy

  set aggregatetreasure sum [treasure] of cops ;; this is the aggregate amount of treasure
                                                   owned by cops at each tick
  print aggregatetreasure

  set collectedtax  sum [tax] of friendly-citizens ;; this is the aggregate amount of
                                              tax collected by friendly citizens at each tick

  print collectedtax
```

```
set aggregaterobberycit sum [robberycit] of stealers ;; this is the aggregate amount of
                                                        robbery stolen to friendly citizens at each tick


print aggregaterobberycit

set aggregaterobberygreed sum [robberygreed] of stealers ;; this is the aggregate amount of
                                                          robbery stolen to greedy citizens at each tick

print aggregaterobberygreed

set aggregaterobbery aggregaterobberygreed + aggregaterobberycit

set aggregatewage sum [wage] of cops ;; this is the aggregate amount of wage
                                                        owned by cops at each tick

print aggregatewage


ifelse count stealers >= number-friendly-citizens
[set reproduction-threshold exp((count stealers)^ 0.5) - exp((count stealers)^ 0.10)]
[set reproduction-threshold intercept-reproduction]   ;;this how variates the functional form of the
                                                          threshold reproduction in order to keep
                                                        into account the crowding effect and
                                                        moderate the increase of the number of
                                                    stealers
end
```

EXPERIMENTS

BASE FRAMEWORK

SET UP:

We assign **income according to a normal distribution**. The **average** income in both populations is **500** and it is a completely arbitrary number (we can choose between 0 and 1000). We set the **standard deviation at 125** in order to have an equilibrated distribution between high-income and low-income population profiles.

In the first experiment we set-up a world in which the **number of cops is 29**. That is the 9% of the cooperative population. This percentage is quite reasonable according with the theoretical framework of our model: in fact we suppose that only the low-income population prefer to become cops. This hypothesis is represented in practice by the fact that we set the **threshold of income under which friendly-citizens change breed in cops at 350**, i.e. the 70% of the average income in the population.

Then we ignore the possibility that cooperation produce positive externalities, and we set the **interests rate equal to 0.03 for both friendly-citizens and greedy-citizens**.

The greedy-citizens' cost structure is given by an initial investment plus a marginal cost, this last is repeated at each tick. In this way we want to represent the fact that the total cost consists of an initial expenditure in weapons and in hiring the body-guards, then at each time the citizens have to pay the wage of the body-guards. What's more, the cost is a linear function of the total number of stealers at each time. The **coefficient which determines the initial investment** is higher: it varies between 0 and 5, with increments of 0.1 and, in this experiment, **we set it at 1**, while the **coefficient of the marginal cost** varies between 0 and 1, with increments of 0.01 and we set it **equal to 0.01**. As a result in the first tick the greedy-citizens spend an amount equal to 1,1*(number-stealers) of their initial income, then, since the second tick on, they will spend 0,01*(count-stealers) of their income.

We create **237 stealers**, i.e. the 40% of the entire population.

We fixed the **tax rate at 0.30**: it's in the middle between the actual level of taxation on income in Italy, which is around 45% and the taxation on finance investments' return, which is at 20%.

Finally we set the **first reproduction threshold at 1000**, that is the double of the average income of the citizens. When the number of stealers will overcome the half of the population, the threshold will start to increase according to an exponential function of the total numbers of stealers.

Here we show how appears our world after the set-up.

In the following table we show the data collected throughout experiment. In order to be able to observe the evolution of the aggregate data, we stopped the "go" after the first tick, then after the 10th tick, then after the 100th and we definitely stopped the experiment at the 500th, unless the model stops by itself before, because all the greedy-citizens or all the friendly-citizens have lost all their income.

	SET-UP	TICK 1	TICK 10	TICK 100	TICK 500

Agg. Income of friendly-citizens	99, 556	100, 994	122, 686	713, 691	2.23E9
Agg. Income of greedy-citizens	75, 481	76, 247	93, 186	883, 443	9.45E10
Aggregate treasure	0	0	461	1, 554	6.73E8
Collected tax	42, 667	915	1, 104	6, 452	2.01E7
Agg. robbery of citizens	0	652	3, 436	66, 212	8.11E7
Agg. robbery of greedy	0	787	4, 676	88, 049	1.64E10
Agg. wage	5, 915	48, 582	120, 018	1,127, 596	7.29E11

GO:

Let us observe the evolution of each aggregate.
The initial value of aggregate income of friendly citizens is 99, 556, which is larger than the greedy citizens' one, even if the distribution is symmetric, as it is shown on the plot below.

In the histogram above it is plotted the initial income distribution. As you can see there is a huge variation around the average. It is important to notice that in the plot of the friendly-citizens the distribution is truncated: this is because we have transformed all the friendly citizens with initial income below 350 in cops and we have change their initial income into wage. In this way we have removed them from the population of friendly citizens.

The plots below show the trend of the aggregate variables printed at each stop.

At the 1st tick.

The path of the two aggregate incomes increases constantly parallel until the 10th tick and over.

At the 10th tick.

It is worth to notice that the **collected amount of tax** after the set up decreases sharply, this is easy to explain: it is because at time zero we tax the initial income, which is a sort of initial capital with which each citizens is randomly endowed, while in the following ticks we will tax only the return from investment which will be always a fraction of the initial capital. Nevertheless it can happens that, after many ticks, income earned by friendly-citizens is so high, that return on investment at each tick will overcome the initial endowment. But we wont see this phenomenon in this experiment since we stop too early.

We can see that at the first tick the **aggregate amount of treasure** is zero, while both robbery stolen to

friendly citizens and robbery stolen to greedy citizens is positive. This is because the number of cops in the world is only the 9% of all population, then is harder that a stealer meets a cop than any other citizen.
We can notice that **aggregate robbery stolen to friendly** citizens is always lower then the **amount of robbery stolen to greedies** from the 10th tick on.
This result can be explained as follows: at the beginning greedy citizens have a double protection, everybody exploit the protection of cops, exactly as the friendly citizens, even if they don't have paid for them. This is perfectly consistent with the fact that police service is a public good, that is greedy citizens are free-riders. But at the same time we have to keep into account that the 9% of friendly citizens has become cop, and in this way untouchable by stealers, then the probability for a stealer of meeting a friendly citizen reduces. Another fact in favor of this thesis is that we can see that exactly when the robbery stolen to greedy eventually overcome the robbery stolen to friendly citizens the amount of **aggregate treasure starts to be positive and to increase**.

At the 100th tick

We can see that between the 10th tick and the 100th there is a first moment in which both robberies increase exponentially and then stabilize, keeping on to be positive but at a quite constant level. This fact can be explained by the function which determines how the stealers reproduce themselves: in fact, after a while, when the amount of booty that each stealer took begins to be large enough they start to reproduce, but then intervenes a sort of crowding-effect and their reproduction rate slows down.

Besides we see that at the 100th tick the aggregate amount of "greedies"' income is higher than the aggregate amount of "friendlies"' income. The overtaking happened some ticks before.
The reason for this overtaking is not random, because we can verify that this trend starts in this point, but then keeps on, at least until the 500th tick, as we can see in the plot below. Then we can state with quite strong evidence that in the long run, given the hypothesis of the model, greedy citizens are advantaged and their aggregate income grows more than aggregate income of friendly citizens.

Since they are richer in absolute value, the aggregate amount of robbery stolen to greedy citizens is higher, but the important fact is that also in percentage inequality persists: in fact robbery stolen to greedy citizens is the 17% of their aggregate income, while robbery stolen to friendly citizens is in percentage the 3,6%. And this again can be explained with the fact that stealers have a probability of meeting a greedy which is of the 10% higher than the probability of meeting a friendly. But at the same time expenditure of friendly citizens increases each time, independently on the number of stealers, while the expenditure of greedy is very low if the number of stealers remains constant, as it seems to be from tick 100th and tick 500th. Because of the functional form of the tax and the price.

Finally what is the effect on the income distribution?

As we can see from the plot above, the distribution of income in both populations becomes more unequal then what we had set. In particular we have only one huge mass of people with zero income and then a large variation. There are few people with very high incomes, we can see that the range is far more large then what we had at the beginning. Besides we don't have a middle income class, it seems that there is a continuum distribution of different level of income between zero and ten millions, with very few people for each possible amount.

Now let check what happens if we rule out all the cops.
The table below shows the results I found.

	SET-UP	**TIX 1**	**TIX 10**	**TIX 100**	**TIX 500**
Agg. Income of friendly-citizens	102, 589	103, 907	123, 776	735, 689	2.3E9
Agg. Income of greedy-citizens	77, 594	78, 655	93, 996	908, 017	9.5E10
Aggregate treasure	0	0	0	0	0
Collected tax	43, 967	943	1, 114	6, 651	2.1E7
Agg. robbery of citizens	0	836	2, 156	111, 889	5.2E8
Agg. robbery of greedy	0	556	1, 958	57, 872	2.0E10

The initial distribution with no-cops.

As you can see, if there are no cops the friendly-citizens' distribution is not truncated. The two distribution are similar but not identical, because the assignment is random.

At the 1st tick:

At the 10th tick:

After 100th ticks:

At the 500th tick:

The trend is exactly the same. But does magnitude change?

In the experiment (1) from tick 1 to tick 10th friendly citizens' income grows of the 1,4%. While in the second experiment only of the 1,2%. From tick 10th to tick 100th the trend changes: in the first experiment friendly citizens grew of the 481% while in the second 494%. And in fact in the end in absolute value they are richer in the second experiment. But let us consider the income per capita: in the second experiment friendly citizens are 300, while in the first they were only 271, then the per capita income at tick 100 in the first experiment is given by 2,633,546,125 in the second experiment is 2, 452, 296, 667: that means it decreased by the 83%.

Exactly the same holds for greedy citizens in terms of growth, but they are in the same number, then they are richer in the second experiment.

However if we look at the aggregates of the robberies we see that they are far higher in the second experiment than in the first. The amount of robbery stolen to friendly citizens is 8.11E7 in the ex.1 and 5.2E8 in ex.2. With regards to greedy citizens is 1.64E10 in ex.1, 2.0E10 in ex.2. In other words the amount of income stolen to friendly citizens is now increased by 541% with respect to before, while for greedies only by 21% .

To sum up we can see that if no body becomes cop in the friendly population they will have a quicker growth in returns on investment. But considering the income per capita and adding to the income of the plain-citizens the income earn by the cops in form of treasure, which finally in the first experiment is of 6,73E8, (higher than the aggregate robbery stolen to the friendly citizens), we can see that they are far more richer when they hire cops between low income citizens.

While for the greedy citizens things do not change a lot. Then we had overestimated the role of the free-riding in improving the growth of the greedy. The presence of cops is an advantage for friendly population because they are everybody protected and the probability of being attacked by a stealer decreases, since they are less in number then “greedies”.

MANY COPS

	set-up	Tick 1	Tick 10	Tick100	Tick 1000
Aggregate friendly income	78,511	78,718	94,425	570,557	1.79E9
Aggregate greedy income	77,533	78,728	94,358	973,660	1.00E11
Aggregate treasure	0	511	931	19,172	3.00E8
Collected tax	33,648	721	850	5,135	1.61E7
Aggregate robbery friendly	0	931	1,404	88,700	4.22E8
Aggregate robbery greedy	0	420	1,501	114,382	2.52E10

Set up

In this setting the only variable that changes is threshold for becoming cops: it increased to 450. This means that more citizens will have an income under the threshold and therefore there would be more cops. In fact they are 99 (before 29).
In the set up we observe aggregate incomes of cooperative citizen and greedy citizens being very similar: 78,511 and 77,533. Collected tax is 30% of aggregate initial income of cooperative citizens, while greedy citizens pay more than 237 for buying weapons.

Tick 1
After one tick we observe an increase in both citizens' incomes: but cooperative citizens seems to be more affected by stealers and therefore their income increases less. Collected tax is reduced because now only new streams of income will be taxed. Cops start to recover the booties.

Tick 10
After ten ticks we observe that both incomes move together, they are equally around 94,500. Treasure of cops and tax collected from citizens increase because there is generally more richness. It is worth noting that, because incomes are more similar, also the amount of robbery that stealers take from the two agents is close.

Tick 100
Now stealers overcame reproduction threshold: in fact they are 342 (in the set up they were 237). The latter went up following the exponential function defined in the code ("crowded" effect). Greedy citizens income increased substantially more than cooperatives. Growth rates are 9.3% and 5.0%. Also treasure and collected tax increased substantially, but less proportionally to income. Consistently with the difference in incomes, the amount of robbery stolen to greedy citizens is higher: 114,382 v. 88,700.

Tick 500
After 400 hundred ticks the trend shown before is confirmed. Income of greedy citizen increased much more than cooperative citizens income. Actually income distribution among citizens are different: there are 90 greedy citizens which lost completely their incomes, while for cooperative citizens this number is 59.
What we suppose from the first model, is that because breed cops is an "evolution" of breed friendly citizen, in the long run cooperatives will meet with a lower probability stealers. On the other side greedy citizens long run costs are lower than cooperative citizens'. Finally we cannot exclude a role for the "free-riding" effect, but from the previous experiment we know that it is not determinant for the different growth rates of aggregate incomes.

POSITIVE EXTERNALITY

We have in this experiment taken into account a plausible positive externality that we assume to come from the existence of a network of relations and cooperation, generating a "social capital" within the cooperative society, which is labeled as "friendly citizens" in our model. In order to catch the different results coming from the assumption of the existence of a social capital effect we have incremented the variable "interestfriendly", namely the interest rate representing return on investment for cooperative citizens. Therefore, we gave to cooperative society a substantial advantage with respect to "greedy citizens", however this is coherent with the assumption of the model on different behavior of the two "breeds" and furthermore we thought that it was important to consider such an effect since it is becoming an always more important concept in our economy, that is pervasively influenced by knowledge and communication, both enhanced by cooperation.
A part the interest rate variation, the other variables have been kept equal to the ones of our comparative model, namely the first one we have analyzed, in order to be able to have a reliable comparison on the variation of the results.
A picture of the set up situation:

After 1 tick :

Since from the first tick our expectations were confirmed. The growth rate of the "friendly-citizens" breed seems to be more significant, boosted by the higher R.O.I mirroring the presence of a form of social capital within this society. The "greedy-citizens" breed instead reflects a slower growth rate, which is due to the absence of a network of relations and cooperation among the members of this society, in fact as already mentioned in our introduction, they only think to themselves. The indicators for aggregate confiscation of

goods stolen is at zero yet and aggregate booty for each breed respectively are still very low.

After ticks 10 :

The situation is stable in terms of growth rate comparison for the two societies, we are now able to compute some calculations using the data collected in our table. For what concerns “friendly-citizens” they grew between the first and the tenth tick by a rate of the 33.5 % . This is less than the interest rate premium we assigned them, however the reason why this happened, is going to be explained in a while. The “greedy-citizens” growth rate measured on the same time span has instead been of the 19.1%. So the next question could be, why did they grow two different percentages rate with respect to those we assigned them by assumptions of the experiment? The answer has to be searched within the criminal activities perpetrated by the breed “stealer” on behalf of both other two breeds. Between the two ticks considered, the overall rubbery grew from the 0.42% to the 21.9% of the richness accumulated by the two societies in aggregate terms. This is what hit both growth perspective of the two societies, slowing them down.

After 100 ticks :

After one hundred ticks trend seems to be confirmed. The premium assigned to the presence of social capital within cooperative society plays a role and leads them to a far more wealthy aggregate data. Robbery seems to be stable after the powerful enhancement observed in the first ten ticks, the reason being already explained. The only novelty is that cops have started to confiscate booties to the thiefs, even if in a limited amount with respect to the aggregate robbery accumulated in the meanwhile, namely the 4.82%.

After 350 ticks :

We noticed that the two distributions of income started to reshape with the two medians on the zero income, however with twenty-one more citizens attacked from the “wolves” for the greedy-citizens population that have also in the mean while distributed her wealth along a long thin tail.

After 500 ticks :

We captured a picture of how our world evolved during these five hundred ticks. The number of wolves has improved much. The sensation is confirmed by our counter :

From the very beginning the number of wolves has increased by 328 units, and this result is well understandable when we take a look at our aggregate indicators movements, stopped as usually at the five hundredth tick. We shall see that to support our previous observation the exponential growth path of the friendly citizen has been mirrored by an equally strong growth of amount of rubbery on their behalf.

The median of income distribution signals that more zero income individuals are present in the greedy-citizens breed, whose tail of their income distribution shortened, hence their society is partially formed by a class of zero and low income citizens :

Conclusions :
It seems that social capital assumption leads to a net result in favor of those who cultivates it. Of course our strong assumption of fixing an higher R.O.I played his part, however further attempts in experiments of this kind could be an interesting research field, and a reshaping of our model in a more addressed direction could be taken into account, so as to be able to catch such an effect more efficaciously.

TABLE OF THE OBSERVATIONS

	Set up	Tick 1	Tick 10	Tick 100	Tick 500
Aggrecit	99808,87	102874,62	137389,69	2810800,72	2.07E12
aggregreedy	78243,26	79546,30	94796,68	907581,47	9.86E10
aggretreasure	0	0	0	8385,71	9.95E8
Collected tax	42775,23	1549,53	2060,84	42162,01	3.10E10
Aggregate robbery cit	0	427,56	43491,27	140603,76	1.18E12
Aggregate robberygreed	0	333,26	7429,83	33423,40	5.06E9
Aggregate wage	5441,54	48216,78	64056,93	1581302,27	1.46E12

UNEQUAL INCOME DISTRIBUTION

SET UP:

Now we distributed income randomly according with a normal probability distribution function, but we set a **standard deviation at 250**, that is twice as before.
In other words we have societies far more unequal then before.

Ceteris paribus we will expect that **we will have a greater number of cops**, because more people of the friendly society will fall below the cop-threshold and, at the same time, more people in the greedy-society won't be able to pay for police and then will remain unprotect.
As a result **friendly- citizens will be more protected** than before and then they will suffer less attacks by stealers and they would be **richer**, while **greedy citizens will be more attacked** and then they will improve less, even if they can exploit the protection of cops as free riders.

Let us see what we have observed.

The initial distribution are flatter than before. If we assume that in principle the two distribution are very similar, here we can see that the part of income of friendly citizens that is truncated is greater than before.

The first expectation is fitted: cops now are 80, then 51 more than before. Now they are the 26% of the friendly population. They have increased of the 175%.
Stealers are still 237, and at the end of the experiment they will be 300. Exactly as before they increase at first, but then remains constant in number because of the crowding effect prevails.

In the table below are shown the data collected in this experiment.

	SET-UP	**TIX 1**	**TIX 10**	**TIX 100**	**TIX 500**
Agg. Income of friendly-citizens	96, 371	96, 318	115, 267	868, 928	6.82E9
Agg. Income of greedy-citizens	86, 227	88, 369	107, 241	1, 422, 855	1.08E10
Agg. treasure	0	1, 267	1, 267	23, 099	7.52E7
Collected tax	41, 302	885	1, 037	5, 735	4.50E7
Agg. Robbery of friendly-citizens	0	810	26, 188	37, 422	1.35E8
Agg. Robbery of greedy-citizens	0	503	75, 304	91, 234	1.86E7
Agg. wage	10, 878	76, 391	84, 853	4, 679, 296	1.38E10

At the beginning the data give reason to our expectations: from the first tick to the 10th tick the robbery stolen to the greedy-citizens is larger than the amount of income stolen to the friendly-citizens. Both in absolute value and in percentage: the stealers take the 70% of the income of greedy and the 23% of the income of the friendly citizens. On the other hand the income of friendly citizens increases of the 19% between 1st tick and 10th tick (in base framework was 22%), while the growth rate of the income of greedy citizens between 1st and 10th is equal to 21% (in base framework was 22%).
Both grow slower with respect to the first experiment. Instead between the 10th and the 100th friendly grow at 6,5% (in base framework was 4,8%), that is growth rate decreases, but at a decreasing rate with respect to base framework. While about greedy citizens in this experiment between the 10th and the 100th they grow at the 12,26% rate (in base framework was 8,48%).

To sum up we can say that: both populations increase at a positive rate between tick 1 and tick 100, but at a decreasing rate. However in this experiment growth rates slow less than before and this is particularly true for greedy citizens.
This is apparently wrong with respect to our expectations, but we have to consider another feature of our model: people invest. Then if it is true that on average greedy citizens are less protect, on the other side they are also richer, because, poor greedy citizens did not spend for weapons, and therefore, since the beginning, they have a greater capital for investement. What's more they are

free riders and now the all society is better protect because the number of cops has increased a lot.

At the 10th tick.

Following this path greedy citizens recover their initial disadvantage and at the 100th tick they have reached and already overtaken the aggregate level of income of the friendly citizens.

At the 500th tick.

What about distribution of income?

Again, the result of the presence of stealers in the population is a huge increase in the number of the proletarian. And with respect to the first experiment we can see that the society most damaged by this situation is the greedy one: they have 160 more proletarian then before at the 500th tick, it's the 90% of the entire population! While before it was the 36%. What's more there aren't any mass point

at very high level of income. In fact also the aggregate level of income is lower than in base framework: 1.08E10 v. 9.45E10, that is, it decreased by 88%.
On the other hand the friendly population is more preserved: only the 30% of the citizens are with zero income, and if we consider also the part of friendly that has become cop, then the percentage lows at 22%: that is the police force is also a sort of welfare system, because it guarantees a wage at the poorer part of the population, and they will always survive. The aggregate amount of income of the friendly citizens before was 2.23E9 at the 500th tick and now it is 6.89E9, then it has increased of the 208%.

Distribution at the 500th tick.

STEALERS REPRODUCE EASILY

	set-up	Tick 1	Tick 12	Tick 34	Tick 109	Tick 165
Aggregate citizen income	100,989	101,911	125,822	195,551	892,920	2,812,689
Aggregate greedy income	79,299	80,022	99,576	158,500	4,567	14,123
Aggregate treasure	0	0	0	4,285	13,410	18,600
Collected tax	43,281	928	1,136	1,759	8,036	25,314
Aggregate robberycit	0	1,198	3,237	2,898,994	6,268,535	7.53E7
Aggregate robberygree d	0	944	2,759	2,963,654	5,855,139	5,852,401
Aggregate wage	5,713	48,994	60,141	642,695	3,641,445	3.68E7

Set up
In this experiment we change one important assumption of the model. Stealers can reproduce themselves again with an exponential threshold , but the latter is sensibly smaller.

```
ifelse count stealers >= number-friendly-citizens
  [set reproduction-threshold exp((count stealers)^ 0.25) - exp((count stealers)^ 0.05)]
  [set reproduction-threshold intercept-reproduction]
```

Every other variable is equal to the basic setting. Interest rates, amount of tax, initial number of stealers (237) and threshold for cops.
Threshold cops: 350

This determines an initial amount of cops equal to 28. Initial aggregate incomes of cooperative and

greedy are consistent with our previous experiments: greedy are paying more for weapons and therefore their aggregate income is smaller: 100,000 v. 80,000.
What do we expect from this new setting?
First we imagine that the model will last less ticks, because if stealers reproduce more it will be easier that aggregate amount of one of the two breeds will go to zero. But which one of the two? And will the reproduction of stealers completely offset the "crowding" effect given by threshold?

Tick 1
After one tick things are exactly as we expected to be: aggregate incomes increase at the interest rate level minus taxes for cooperative and marginal cost of weapons for greedy; stealers consistently take a little bit more robbery from cooperative, because their aggregate income is bigger.

Tick 12
After 12 ticks stealers did not started to reproduce yet. The two populations are investing and growths of their incomes are quite similar as illustrated below.
Aggregate income of cooperative goes from 101,911 to 125,822. Growth rate: 23,46 %
Aggregate income of greedy goes from 80,022 to 99,576. Growth rate: 24,43 %

Tick 34
Since few ticks we start observing an increase in stealers. They are now 2407, from 237 they made a jump of plus 915%! Their reproduction threshold increases but less than in the other experiments, this decreases substantially the "crowding" effect.

As we can see in the picture below stealers are not discriminating among breeds: the amount of robbery stolen to cooperative and greedy increases exponentially! (violet line is exactly above black line)
Actually although aggregate income of cooperative citizens is still higher than greedy one (195,000 v. 158,000), the amount of robbery stolen to greedy citizens is now higher (2,963,654 v. 2,898,994).

Tick 109

Now the amount of stealers "only" doubled compared to before. We are observing the "crowding" effect at work! In fact, after the reproduction threshold for stealers adjusted, the amount of robbery stabilized. What is really interesting to observe is that stealers succeeded in taking incomes from almost every greedy citizen! Looking at the distribution of income in the picture below, it is worth noticing that 299 greedy citizen have zero income.

Tick 165

In following ticks, we observe aggregate robbery of citizens increasing. It is a process with regularities, in which, when stealers overcome threshold, robbery increases substantially. After the threshold adjusted, we observe again a “calm” period, in which cooperative citizens continue investing. Greedy are represented by one “stoic” survivor, which continue investing until some stealer will meet him. But she actually seems to be pretty lucky. As we can observe from the picture, aggregate robbery of greedy stay constant, while the magnitude of the only increasing variables is quite different.

Aggregate robbery of citizens: 7.53 E7
Aggregate income of citizens: 2,812,689

Tick 244
The trend showed before is confirmed after many ticks: until the unique greedy survivor is captured, aggregate robbery of citizens will follow a more or less regular path. When stealers overcome the threshold they start reproducing and we observe an exponential increase in robbery, then threshold adjusts and for some time they will no more able to increase so much their robbery.

CLOSER TO REALITY...

After having gone through a series of experiments mainly grounded on our willingness to test the efficaciousness of our model, we wanted to try what would have been the outcomes after having inserted in our control variables parameters coming from the real world. Namely, we used data regarding Italian statistics about criminality rates, number of prisoners' population, number of police officers and agents belonging to the Ministry of Defence but acting as police officers on the national territory (Carabinieri), average national incomes and its distribution, finally average tax rate on personal income and average estimated return on private investment. We collected economic data that we use to determine our model using statistics of 2008 but referred to the year 2007(before the beginning of the financial crisis). The data regarding fiscal contributions are from the reports of the 2008 referred to the taxable income of the fiscal year 2007. For the sake of affordability of our demographic data, we used the one from 2008.
All the informations about the datasets used are collected in the references at the end of our experiment .

Some data :
This experiment does not pretend to give any result which could be comparable with reality, however it could answer to some interesting and curious questions, such as: what if in our country it would be possible not to pay taxes at all, for say half of the population ? What if they would be let free to get armed and defend by their own ? Would they benefit from the free ride principle ?

To answer these questions, we tried to replicate as much as we could an economic and demographic situation close to the Italian one.
The data have been rescaled to our initial population of 1,200 agents. Data from a E.C.B. working paper allowed us to fix the average private investment return at 2.66% in Italy. While using an article of a reliable financial news paper, the "Corriere Economia" we had a summary of the fiscal situation at the fiscal year 2008. Average income was at 18,892 (before taxes), for standard deviation of income we used a comprehensive parameter taking into account overall households returns. This was done to have a distribution of accumulated wealth which could fit, at least initially, the real Italian distribution around average households ownerships. For what concerns demographic data about the Italian number of police officers and in order to fix an initial realistic percentage of criminals within our population we used reports coming from Eurostat. Using the number of agents and prisoners per one-hundred thousandths of populations we had our data by mean of a simple proportion.

Set up :
Let us start from our rescaled data.

Which led us to the following initial income distributions :

Note: the upper bound of our distribution corresponds to incomes above 200,000 euros, which are in Italy only the 0.02%.

Here a picture of our initial scenario :

After the first tick it is already explicit the advantage of getting armed instead of having to pay taxes. In fact after some not easy at all research on the average price for a pistol, we have found out that its cost represents an initial fixed cost in the amount of a bit more than the 10% of our average income. The marginal cost for ammos is risible. The different initial intercept reflects this result :

After 10 ticks the situation is stable, still the " tax evasion " seems to pay, and poor cooperative citizens pay the burden of guaranteeing a security system to everybody.

After one hundred ticks situation gets even worst for cooperatives which are unable to recover their "disadvantage" , with respect to the selfish citizens. To be clear, we cannot extrapolate any real conclusion applicable to real world. Limits due to our model only allow us to say that under the above said conditions a tax evasor who knows that he can be selfish since sure he won't get any fine or won't be arrested is able to accumulate a far higher amount of wealth.

However, such an amount of wealth poorly protected (in our model we have a fixed amount of cops), attracts those who are intentioned to rob. In our model we have up to now thought to robbers as physical

units, however what they do really represent are crime committed per tick. They grow more the more they can be freely increase their wealth. Under our model conditions robbery was easily perpetrated and at tick 186 stealers increased vigorously up to the number of 515 at the tick number 250. It could be interpreted as an explosion of criminality rate within our model. The fast growth generated by tax evasion has not allowed an adequate growth of police forces to defend the wealth created. Only a higher amount of police officers could have prevent such a strong growth of criminal activity, that in our model would have been slowed down through confiscation of booties.

This was an impressive result to us, criminality achieved a huge amount of wealth subtracted to our citizens, their disposable income, used to replicate criminal activities strongly damaged the economic growth of our agents, particularly the one of cooperative citizens, who already suffered a slower growth rate.

At tick number 395 we decided to report here our last significant observation, since the trend was constant and anything did not change any more. The selfish citizens prevailed, on behalf of the cooperative ones. They enjoyed at some extent the protection of the initially adequate police system, generating an attractive amount of wealth for criminality, that eventually spread in our society, which was not able to have enough police confiscations slowing down the rate of increase of attacks toward citizens.

As a consequence, cooperative and not armed citizens resulted to be the poorest in our model. Criminality collected a huge amount of wealth, however risible with respect to the one gained by self defended and tax evading citizens. Our agent world is far more violent than it was at the beginning, only those who where selfish seem to prosper, however the strong assumptions of an equal number of selfish and cooperative citizens together with the limits of our model could suggest that further experiments would have to be done and that our model should become even more dynamic, in order to be able to have quick and strong response to an increase in the criminality rate .

PAGE 10

	Set up	Tick 1	Tick 10	Tick 100	Tick 250
Aggrecit	17712,48	17929.17	20724.71	85518.56	841191.14
aggregreedy	25588,71	26194.58	32967.60	332764.19	1.36E7
aggretreasure	0	0	0	0	0
Collected tax	10856,03	181.99	209.48	864.42	8502.76
Aggregate robbery cit	0	75.41	119.77	2231.11	1047845.94
Aggregate robberygreed	0	89.74	174.52	5595.99	8264702.06
Aggregate wage	207.84	11063.88	12805.67	53833.42	537450.80