Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Lecture with Computer Exercises:
Modelling and Simulating Social Systems with MATLAB

Project Report

Avoiding 1984 coercion's limit

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Zurich
December 2016

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Contents

1 Abstract

With this work we want to investigate the rebellion dynamics as a function of the government's actions directed to maintain stability.
We restrict those actions to an amount of two, namely, convincing the people of sustaining it - through what we will summarize as propaganda - or by brute force - which would be the police action. Those actions both do lead to stability, but offend freedom. A society as the one described by *George Orwell* in his famous novel *1984* presents exactly this problem: preservation of the government is due to both, significant brain washing and active force application. The dilemma lays in the balance between what a system will do to maintain itself and the consequent loss of liberty. We would like to seek a bottom limit for the government's actions, as the optimum point between the stability of the political form that we obtain with a high investment and the positive aspects connected with a low investment such as personal freedom and more funds for infrastructure development.
We approached this problem by creating an agent based simulation, starting from the setup defined by the paper*Modeling civil violence* by *Epstein*, which we adapted for our purposes. Inspired by a second paper *Nation building* by *Alesina* and *Reich* we introduced dependencies from the action of the government toward maintaining a low number of rebels. This was done, as introduced before, with the help of two factors: a value for the investment for propaganda and one for the one concerning the police.
The results have been ordered under different forms. The evolution of the situation can be visualized in a video that show cops, citizens and rebels with different colors in their position in the map. Graphs correlating the percentage of population being either citizens, rebels or cops as a function of time give us the intuitive picture of the development of the social status. In the cases in which it was reached, we characterized the steady state and build correlation coefficient between number of people and different kind of investments, as well as between cops and rebels.
As a conclusion, we did find optimum values. The numerical values of the data are clearly relative, however. Nevertheless, they show the realistic result of a broad range of situations offering near zero rebellions. This means that there exists a limit for the action of the government that should not be overtaken.

2 Individual contributions

This work is the result of a team effort. As a team, we planned the theory and structure of the scripts: what should each part of the code do. In a second moment we divided the coding into two parts, done separately. At the end, we met to read through the code again and use it to perform our analysis and interpret the results. This report is as well a team work. The parts that have been done singularly are specified below.

2.1 Brunner Georg

Georg coded what concerns the time evolution. This includes the randomization of the scanning order on the grid as well as the singular functions that update the cells - being empty or containing a citizen, rebel or cop. He took care of the plots of the population composition as a function of time as well. In the report, he wrote *Chapter 4*, theoretically describing the model.

2.2 D'Errico Cecilia

In the code, Cecilia took care of the part concerning the structure of the data saving - through matrices - and the generation of initial matrices and actors. In addition to that, she wrote some specific functions for the characterization of the grid - relations between cell numbers and coordinates - and the relative grid plot. In the report, Cecilia wrote *Chapter 5*, presenting the implementation of the model.

3 Introduction and Motivations

We based our work on two papers, as it is described more precisely in the next section. We relied on *Epstein* model as a base. This theory described rebellious dynamics with a very general approach, starting from random parameters. The goal was to see certain realistic cyclic behavior - result that has been obtained - as well as to investigate the effect on the system of the values of certain parameters.
We wanted to answer a different question. Inspired by our second paper *Nation-building* by Alesina and Reich, we introduced in the model the influence of the government. Influence always directed to the stabilization of the population, i.e. lowering the amount of rebels. This can be of a violent nature - reliable with the action of the police - or of a preventive kind, such as propaganda.
According to these ideas, we produced a base model that evaluates population dynamics as a function of two constant parameters: propaganda investment, *PI* and police force investment, *CI*. With the help of this model we want to investigate

whether there exists something such as an *optimal investment*, the minimal value for those funds that support stability.
In the first variation of the model we wanted to investigate the influence of the behavior of the people in someone's neighborhood. Therefore we applied some changes in order for a citizen to become a rebel more likely, when being surrounded by more rebels. As a second variation we applied some changes by making the creation of cops more likely to happen, as the number of rebel increases. Our goal was to check whether different generations would develop different behavior as a consequence.

4 Description of the Model

4.1 Brief Review of the Model proposed by Epstein

The model we chose for our project bases on the one introduced by Epstein in 2002[1], whose most important features and insights will be briefly emphasized in the following. For further information we are referencing to the paper itself.
The foundation are two different groups of actors: On the one hand there are the citizen, who may be actively rebellious or not, while on the other hand there is a minority of cops, who represent the central authority and can arrest active rebells.[2]
The citizens properties are summarized in *Table 1.* Whereas cops do not have any properties, but only move on the grid and arrest rebels. They are assumed to be loyal during the whole simulation.
Epstein's main interest was not to record any model parameters or to reconstruct any particular case, but rather he was investigating

> ... whether this highly idealized model is sufficient to generate recognizable macroscopic revolutionary dynamics ...

And indeed his model showed remarkable behavior, when confronted with typical change of variables. One outstanding example he observed is the different reaction to lowering legitimacy.
In the first scenario it was decreased peace by peace, which caused some citizen to turn to active rebellions here and there. However an outburst did not happen, since

H ... Hardship	Accounts for economic, physical misery. It is heterogenous amongst the population. Values are drawn from the uniform distribution on [0, 1]
L ... Legitimacy	The governments perceived legitimacy. It is homogenous amongst the population. (Input parameter)
G ... Grievance	$G = H \cdot (1 - L)$
N ... Net Risk	This is the product of the citizen's risk aversion and his estimated arrest probability
S ... State	G - N > *threshold* be active G - N < *threshold* be quiet

Table 1: The citizens parameters in Epstein's model

[1]Epstein, Joshua M. (2002), Modeling civil violence: An agent-based computational approach, *PNAS*, Vol. 99, 7243-7250

[2]It has to be mentioned that in Epstein's paper two different models were proposed. We focus on the first one, which goes by the name *Civil Violence Model I: Generalized Rebellion Against Central Authority*

those, who became active were arrested very quickly (smooth rise of jail curve). On the contrary, in a second case, legitimacy was decreased suddenly, but in total by a smaller amount than previously, which led to an explosion of actives and correspondingly to a sharp rise in the jail curve.

For further justification of the model above, an empirical sequel was conducted in 2010. The project used incidence data collected by the Political Instability Task Force (PITF) to test the model against it. They found

> ...the model's explanatory to be high ...and robust across a variety of statistical instruments.[3]

4.2 Extended Model for this Project's Purposes

The major difference to the model described above is the introduction of monetary issues. In a very first step we divided the state's expenditure into three different types, namely

1. **CI** ...Cop Investment
2. **PI** ...Propaganda Investment
3. **GI** ...General Investments

where the names are their own explanation. Cop Investment is the percentage of the state's expenditures, which is spent on public order and safety. Propaganda Investment describes the percentage spent on propaganda, while any other expenses are summarized by the term General Investment. The assumption is, that the budget is completely funded by taxes coming from the population, meaning the possibility of saving budget is not given and there are no other sources of income but taxes.
We further assumed, that the state's income has to be constant. This implies that the taxes are a function of total population, or being more precise, a function of non-active citizen, since non of the both, neither cops, nor rebels are paying taxes in our model.
The purpose of those new variables is to define citizen's, as well as cop's properties in a more precise way.

[3]Epstein, Hammond, Klemens, Raifman (2010), Empirical Performance of a Decentralized Civil Violence Model, *Center on Social and Economic Dynamics BROOKINGS*, paper no. 56

4.2.1 Legitimacy

For this we used a relation proposed by Alesina and Reich in their work about Nation building[4], when they had to compare the utility u each individual draws from different governments. For our purposes the function reduced to

$$u = \lambda \cdot (1 - r)$$

where r is a term for the taxes and λ describes the costs for *homogenization*, which we called Propaganda Investment, *PI*. We used this function, to approximate the Legitimacy of our government. Of course, with this relation we can only account for a fractional part of the true term *Legitimacy*, however the results of our simulation suggest that this approximation is not bad. Note that important properties of the parameter *Legitimacy* stay the same as in the original model by Epstein. That is, the distribution is homogeneous amongst the agents and constant over time.
As seen later in *Chapter 5* the term for taxes will be scaled by a factor of 100 in our model. This is only done, due the way we computed taxes, this term is very small and we would not see the effects clearly. The scaling factor will be constant for all simulation we do with our model. One could further observe the effects of r in a sequel to this work.

4.2.2 The Arresting Efficiency

Besides *Legitimacy*, we were able to define parameters for cops. While in Epstein's model a cop arrested a rebel within his vision only given the presence of such, we claim this only happens with some given probability. This probability is a function of two values. Naturally the Cop Investment plays a crucial role, and maybe less obvious, the ratio of active rebels to cops within his vision, ACR. The value computes as

$$\text{Arresting Efficiency} = 0.8 \cdot \left((1 - e^{-5 \cdot CI}) - \frac{1}{1.25 + e^{-0.5 \cdot ACR + 5}} \right)$$

The intuition behind this fairly complicated looking function is really very simple. For small values of the Cop Investment the arresting efficiency will grow very fast, after some threshold, however, it will only slowly converge to a maximum of 0.8. The second part is called a Sigmoid function and only plays a significant role for values of the active to cop ratio above ~ 12, where it decreases the cop arresting efficiency suddenly by an amount of 50%. This means the cop gets overpowered by the shear amount of rebels. For a better understanding the cop efficiency for constant values of CI and ACR can be read from *Figure 1*.

[4] Alesina, A. & Reich, B. (2012), Nation-building, *MIMEO*

4.2.3 Fixed Parameters

Unfortunately, we were not able to find any values for all the constant parameters in the model proposed by Epstein. Since this work is completely non empirical, we had to set them randomly. Thus all fixed parameters are listed in *Table 2*. A particularly crucial parameter, of course, is the threshold, when quiescent citizen turn to rebels. This was mentioned by Epstein, to be a small value. It turned out, however, that for *small* values $\in [0.3, 0.4]$ the percentage of rebels exceeds 80% and more very fast, which we believe to be highly unrealistic. Thus the provided value was chosen.

Simulation Duration	300 Steps
Grid Size	40×40
Percentage of Cops	7.5%
Percentage occupied	80%
Threshold to become a Rebel	0.75
Probability to move	5%

Table 2: Fixed parameters for all of our Simulations

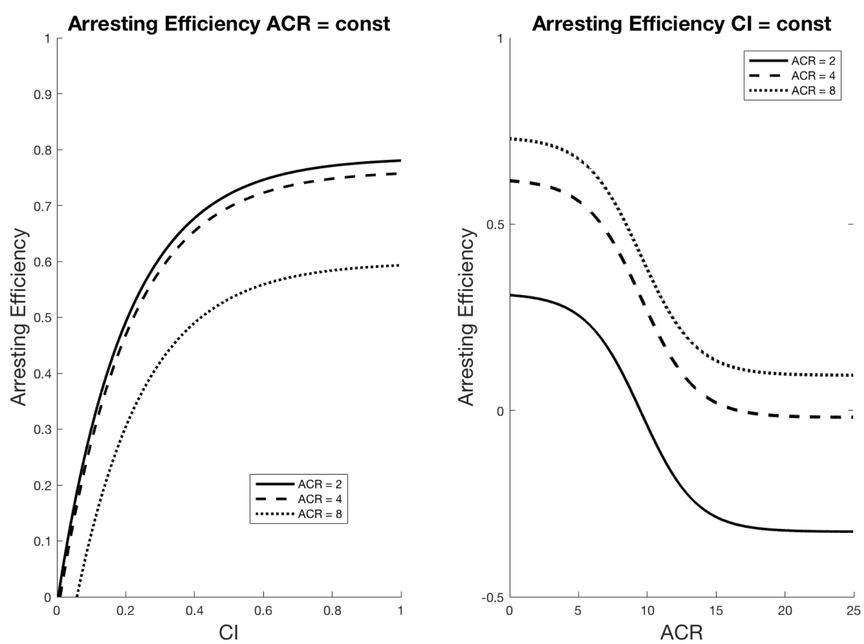


Figure 1: The Arresting Efficiency Function

5 Implementation base

5.1 Fundamental Ideas

While previous projects on similar topics[5] used an OOP approach for implementing the actors and their properties, we wanted to have MATLAB's full power available and chose to work with matrices. The whole simulation lives on a 2 dimensional grid, where each cell is either occupied by an actor or empty. The indices [m, n] of this grid correspond with the column index of the *property matrix*, which in our code will be called *M*. This matrix contains all actors and every of their properties. So for example the properties of an actor, who is located in the second row of the first column of his 5 x 5 - World, would be summarized in the sixth column of *M*.[6] The conversion from column vector of *M* to the actual location on the grid, or vice versa, can be achieved using the functions coordinates.m, respectively cell_number.m
The first row of *M* is the column index itself. Even though, this information is redundant, by doing so we left open the opportunity to extract a single column, without loosing information on the previous position of that actor. This information plays a role, when active rebels are getting arrested, meaning they are removed from the grid and stored in a *jail matrix* - *J* - until their prison sentence has been served. The remaining rows contain an identification number, followed by the specific properties.
An example for the structure of *M* and each single group is given in *Table 3.* It can be seen that the *property matrix* is $M \in \mathbb{R}^{8\times n^2}$, where n is the size of the grid. Initialization can be done using the *create_initial_matrix.m* function.

1	2	3	4
3 . . . Rebel	0 . . . Empty Cell	1 . . . Quiet Citizen	2 . . . Cop
Age	0	Age	Age
Hardship	0	Hardship	Arresting Efficiency
Legitimacy	0	Legitimacy	-1
Grievance	0	Grievance	-1
Risk Aversion	0	Risk Aversion	-1
Net Risk	0	Net Risk	-1

Table 3: The structure of *M* for each type of actor

[5]Gubler, F. & Kaeslin, C. (2012), Folks in Civil Conflicts, *MIMEO*
[6]*M* itself having 25 columns

5.2 The Updating Process

Once the initialization process is done, the grid is updated within discrete time steps, until the end of the simulation. For this procedure great effort was made to avoid any misleading dynamics which could occur when iterating cell by cell through M in order. Our approach is explained in this chapter and sketched in *Figure 2*.

Ordering data In a first step all the column indices belonging to each group are collected and stored in different arrays. This is the aim of the *indicize_people.m* function having a return value of 4 arrays:

E	Array containing all the column indices of M, which are empty cells
CITQUIET	Array containing all the column indices of M, which are occupied by quiescent citizen
COP	Array containing all the column indices of M, which are occupied by cops
REB	Array containing all the column indices of M, which are occupied by active rebels

Randomizing elements within a group Secondly, those arrays are randomly shuffled, which can be done in an elegant way with the help of MATLAB's built-in *randperm* function. One can scan through these arrays to update the members of a single group - in a now random way.

Randomizing between groups However, for the most unsorted procedure it is necessary to randomly pick between groups during every iteration as well. To achieve this we computed the probability to pick each group as following the quotient:

$$P_x = \text{probability to pick group } x = \frac{\text{number elements in group } x}{\text{number elements in the four groups}}$$

,where $x \in \{E, CITQUIET, COP, REB\}$. This information is used to decide the group of the element to be updated by first generating a random number $p \in (0,1)$ and then by relying on the rule described in *Table 4*.

For each time time step we will go randomly - randomization produced as explained - through all the cells of our grid. We will then proceed to update the state of each cell by calling specific functions depending on its state: empty, hosting a citizen or a cop.

Group to pick	Condition
E	$p \in (0, P_E]$
CITQUIET	$p \in (P_E, P_E + P_{CI}]$
COP	$p \in (P_E + P_{CI}, P_E + P_{CI} + P_{COP}]$
REB	$p \in (P_E + P_{CI} + P_{COP}, 1)$

Table 4: Random assignment to groups

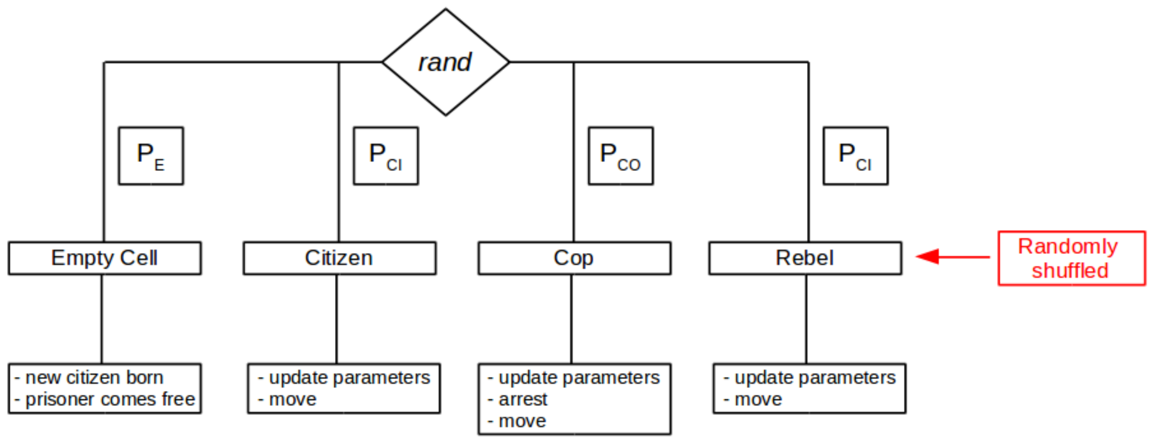


Figure 2: The Updating process

5.2.1 Empty Cells

In each iteration empty cells might stay empty, host a citizen that got out of jail or contain a newly born citizen.

New citizen born In the function called *update_free_cell* if a randomly generated number $d \in (0, 1)$ has a lower value than the fixed probability $PBirth$, then a new citizen will be created and positioned.

Prisoner comes free If there is in jail - represented by the J matrix - a prisoner that has served his sentence and if the cell has not been destined to host a newly born citizen, then the prisoner will be settled in there. As a consequence, at the end of the time step, every prisoner that has served his sentence will be reintroduced on the grid, as long as there are free cells.

If the two above described situations are not satisfied, the cell will stay empty.

5.2.2 Active & nonactive Citizen

The process of updating citizens consists of two parts: updating their properties and eventually moving on the grid.

Update parameters Let us refer to *Table 3* for the structure of a citizen's properties. In our code, we produce those changes with the function called *update_citizen*.

- In eace time step, the lifetime of the citizen - expressed in years but backwards, as a countdown to zero - will be reduced by 1. This accordingly to our interpretation that each time step corresponds to one year. If the life of the citizen has reached the zero value, the cell content will be replaced with empty cell data: representing death.
- Government's legitimacy L is directly proportional to the propaganda investment PI and to weighted *taxes* - following the formula:

$$L = PI - 100 \cdot taxes$$

- Grievance G relates hardship and legitimacy as *Epstein, Hammond, Klemens and Raifman* model defines.

$$G = H \cdot (1 - L)$$

- The agent's net risk N is a function of his risk adversion R, which is a value fixed for the lifetime, and of the presence of cops in his neighbourhood. We proceed by first evaluating this coefficient with the help with a function *CopToActiveRatio* and then by computing N according to the formulas below.

$$P = 1 - e^{-0.2 \cdot \text{CopToActiveRatio}}$$

$$N = R \cdot P$$

- Once updated all the other properties, we can proceed computing the state of the citizen: either quiet or rebellious. This is done with a comparison to a fixed treshold value, as suggested by the *Epstein, Hammond, Klemens and Raifman* model.

$$\text{if } G - N < \textit{treshold} \text{ be quiet, otherwise rebellious}$$

Move In order to make the agent move on the grid, we make use of a previously defined function *move_on_grid* that first checks which cells in the first neighbourhood are free - including the cell the actor is currently in - and then randomly pick one of these cells as the target destination, writing accordingly the data in the M matrix.

5.2.3 Cops

In each time step, we must take care of each cop in three ways: it's necessary to update his properties; with the help of those, possibly arrest; move this actor on the grid.

Update parameters The parameters of a cop are not many.

- In the same way we did for citizens, the age parameter - countdown of the lifespan to death - is updated: reduced by 1. If the cop has reached zero lifespan, he will die and the data of his cell will be rewrote with the ones of a free cell.
- As described above the cop's arresting efficiency has to be computed every time step. As a reminder this is done using the function

$$\text{Arresting Efficiency} = 0.8 \cdot \left((1 - e^{-5 \cdot CI}) - \frac{1}{1.25 + e^{-0.5 \cdot ACR + 5}} \right)$$

Arrest To simulate the arresting dynamics, for each cop his neighbourhood will be controlled and data of his neighbours will be saved. With the probability *Arrest Efficiency* - as described in the previous section - the cop will attempt to arrest the rebels around him: a cop can arrest maximum one person for each time step; therefore, as soon as an attempt is succesful, no other rebels will be controlled. The cop will assign to the unfortunate rebel a sentence time, uniformly distributed value between 0 and a maximum, and the rebel will be stored in the jail matrix J as a quiet citizen and deleted from the grid.

Move The moving dynamics for the cop is identical to the one of each citizen.

6 Two implementation variants

6.1 Social behaviour simulation

In this first variant of our base project, we modified one formula in order to make it more likely for one citizen to become rebel when in the situation of being surrounded by a greater number of rebels. This has been done by modifying the formula that updates the state of each citizen in each time step.
The original formula is:

$$\text{if } G - N < \textit{treshold} \text{ be quiet, otherwise rebellious}$$

, where G represents grievance and N the agent's net risk.
Our modification looks as following:

$$\text{if } G - N + \frac{\textit{rebels in neighbourhood}}{\textit{neighbourhood total size}} < \textit{threshold} \text{ be quiet, otherwise rebellious}$$

6.2 Generations characterization

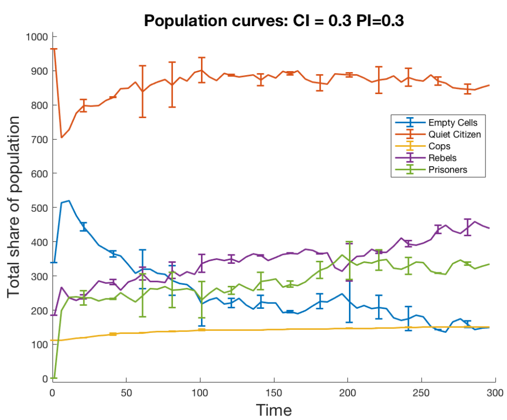
In this second variant we wanted to introduce a stronger dependence between the number of rebels and the number of cops. This has been done by increasing significantly the probability of a cop to be born in correspondance of a greater number of rebels. Since a cop remains a cop for all his lifetime, this could result in differences between generations and we could observe cyclic behaviours.

7 Simulation Results and Discussion

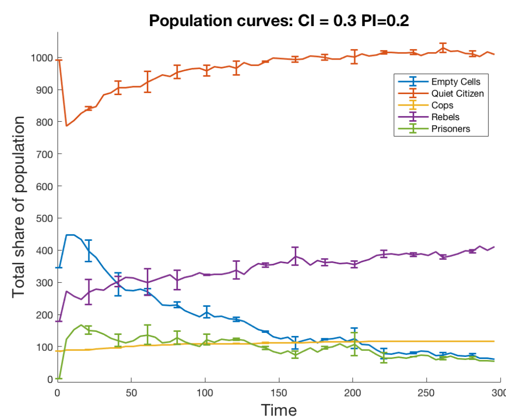
7.1 Base model

7.1.1 Typical cases

In this section we want to show how the parameters we introduced: CI - cop investment - and PI - propaganda investment - affect the behavior of the population distribution.
In *Figure 3 (a)* PI has been decreasing progressively during the years, while CI maintained a fixed value. The numbers at the top of the pictures characterize the initial situation. As expected, we see a slow increase in the number of rebels: the less propaganda is done, the more likely people are to become rebels. In the model, such a change will be reflected in a lower value for the citizen's perceived legitimacy of the government.
Figure 3 (b) refers to the case with a fixed PI and a slowly decreasing value of CI. Again, the effect is visible: the number of rebels increases as time passes, since the cop's efficiency is negatively affected by a lower CI. It also can be seen that the amount prisoners decreases.
To get a more precise idea of the influence of those two parameters, we can rely on *Figure 4*. At time 150 a sudden reduction of PI has been applied: we see the number of quiet citizens abruptly reducing - simulation of the loss of the propaganda effect.



(a) Smooth changes of PI by 0.0075 per Step



(b) Smooth changes of CI by 0.0075 per Step

Figure 3: Affects of changes in CI and PI

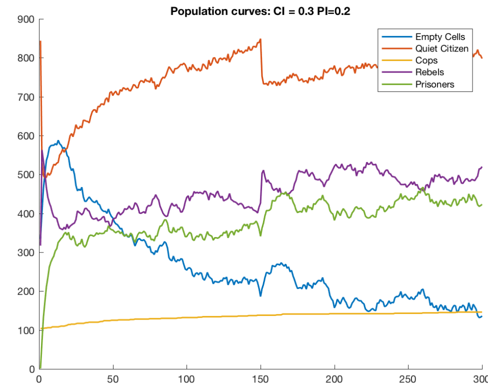


Figure 4: Sudden change in PI by 50%

7.1.2 Correlations between CI, PI and rebels

According to our initial question, wether there are bottom values for the government's investments that satisfy even strict stability requirements, we want to present our data under a form readable in such a way. In *Figure 5* we see the percentage of rebels in steady state (average of the situation at the end of the simulation) as a function of CI and PI. The dark and light blue range corresponds to the most stable cases: no or few rebellions. There exists therefore a range of values for which the number of rebels is significantly low. According to our model, this happens more in relation with CI: a high cop investment succeeds better in keeping the situation under control.

In *Table 5* we see the correlation coefficient between our two parameters CI and PI and the number of rebels - the most important data to describe the system. For the two relations of the rebels percentage vs. CI and PI we see a strong negative correlation. This means that there is an evident relation between the quantities: and that as CI or PI increase, the rebel's number decreases accordingly to such change.

	CI	PI	Rebels
CI	1	0	-0.7641
PI	0	1	-0.9274
Rebels	-0.7641	-0.9274	1

Table 5: Correlation Matrix among investigated parameters in the base case

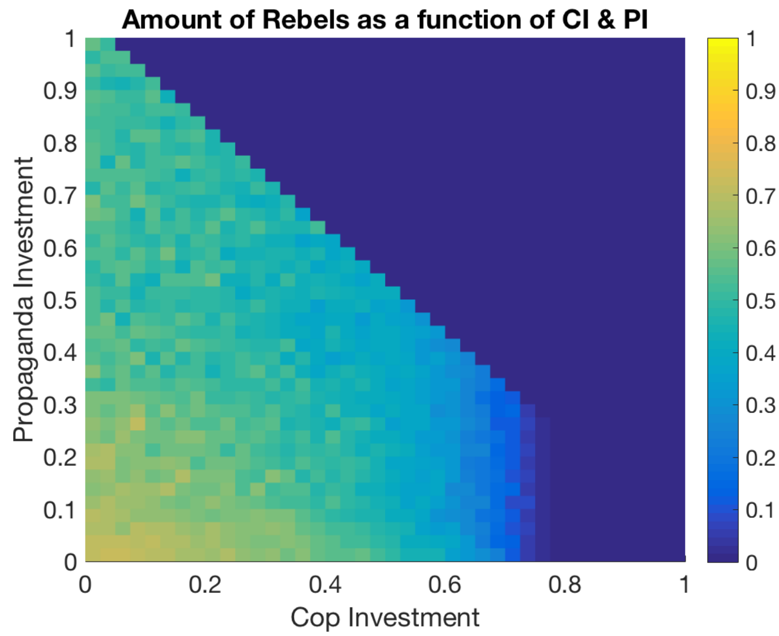


Figure 5: Result of the base model

7.2 Social behaviour variant

7.2.1 Correlations between CI, PI and rebels

Due to the fact that this variant presents a new dynamics compared to the base one - the possibility for rebels to influence other people around them by making it more likely for those to rebel as well - we expect outbursts to happen faster.
This is visible in the graph of *Figure 6*: there is a wider range of CI and PI that presents a high number of rebels in the steady state. From the same graph we notice that, as in the base model, CI influences more drastically the presence of rebels compared to PI.

Table 6 reports the correlation coefficients between CI, PI and the rebel's number. Particularly meaningful here is the correlation between the propaganda investment and the rebel's number: value that shows again a negative correlation, but not as strong as the one of the base model. This corresponds to the interpretation that as social interaction is introduced, the effect of propaganda will be lowered between the ones that are in contact by neighbourhood with some rebels.

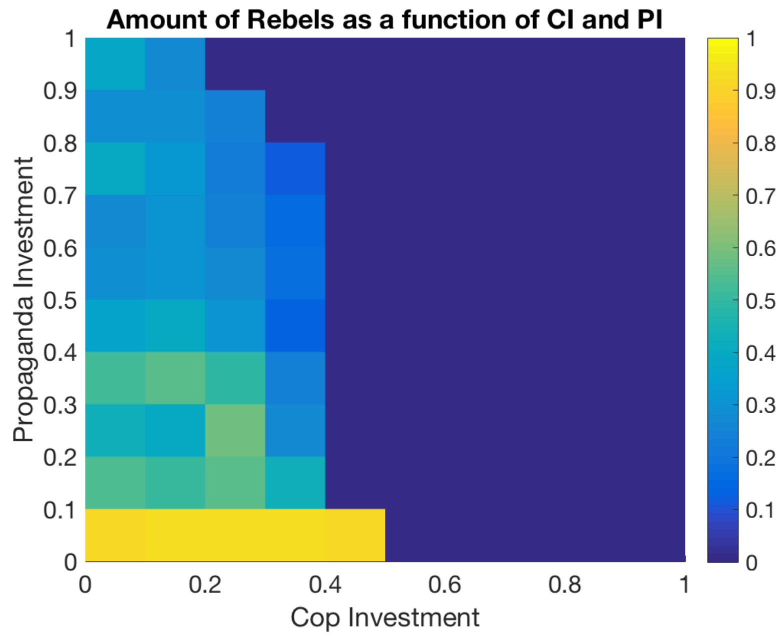


Figure 6: Result of the social behaviour model variant

	CI	PI	Rebels
CI	1	0	-0.8809
PI	0	1	-0.5383
Rebels	-0.8809	-0.5383	1

Table 6: Correlation Matrix among investigated parameters in the social variant

7.2.2 Rebels grouping

In *Figure 7* we extracted one rebel grouping dynamics. In the bottom part of the picture, which shows consecutive photos of the same part of the map, it is visible how the presence of some rebels resulted in the formation of a group of them.

7.3 Generations characterization variant

7.3.1 Correlations between CI, PI, rebel and cop number

To observe the results of the last variant of the model, we once again produced the graph of the number of rebels in the last part of our simulation as a function of the parameters CI and PI. This is shown in *Figure 8*: and to the naked eye it is clearly

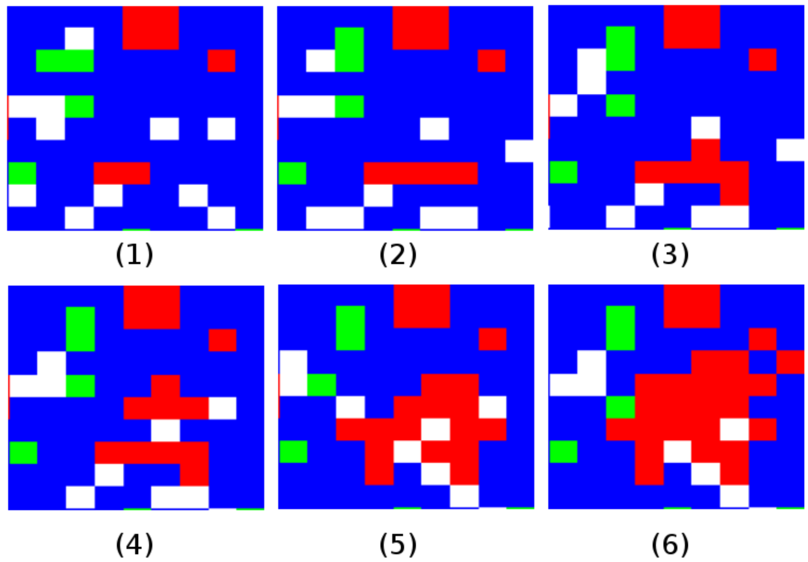


Figure 7: The process of rebellious groups formation (colormap: red-rebel, blue-citizen, white-empty, green-cop)

visible how the stability is better preserved compared with the case of the previous variant. The graph shows presence of rebels just with the lowest values of CI and PI.

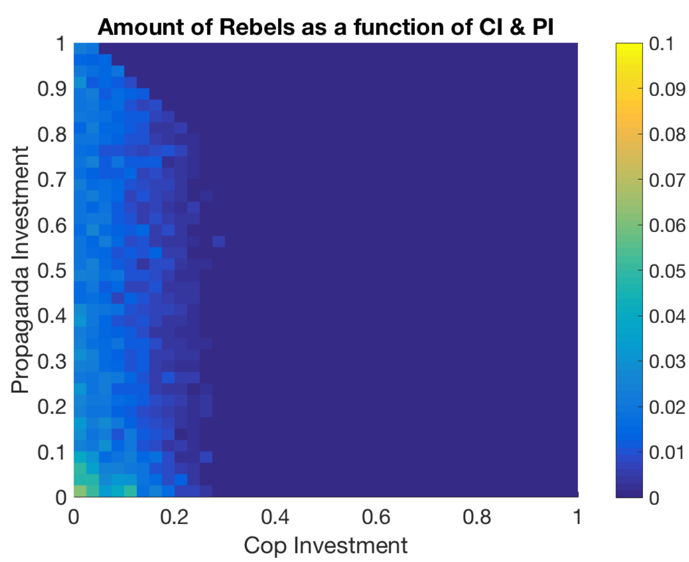


Figure 8: Result of the generations characterization variant

The correlation coefficients presented in *Table 7* show a small positive correlation between the number of cops and the number of rebels. Due to the fact that the value for this correlation cold not be averaged, we decided to insert an approximated one: cutting the last digits.

	CI	PI	Rebels	Cops
CI	1	0	-0.4220	0
PI	0	1	-0.8123	0
Rebels	-0.4220	-0.8123	1	~ 0.25
Cops	0	0	~ 0.25	1

Table 7: Correlation Matrix among investigated parameters in the generation characterization variant

A confirm of the presence of a small correlation between number of cops and number of rebels can be found in *Figure 9*: at time 80-100 we see the number of cops increasing. As a result to that, in time 80-110, we see a sudden decrease of rebels. This trend inverts afterwards, and from time 110 to time 250 we see the number of cops decreasing, as the number of rebels increases. This whole process seems to start again at time 250: actually creating a simple cyclic behaviour - what we would identify with generation differences.

Figure 9: Plot of the population distribution as a function of time

8 References

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