Agent-based modeling of democratic process in the context of economic turmoil: the case of Colombian post-peace accord.

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1 Abstract

The study and modeling of the causes and effects that different political, economical, or even armed conflict can have on the democratic process has an inherent difficulty: the impossibility of performing experiments aimed to quantify the different interactions, and the effect that different policies have on society and on institutions. Computer simulation and compute modeling can be used to fill this gap. In this article we present a bottom up approach, in which we define the basic agents and their interactions, and interpret the aggregate measurable quantities. Specifically, our basic agent is the individual household, and its characteristics are it social connections, income, their legal status, and its voting decision. At each time step, the decision of individual agents are aggregated to calculate the income of both the government and the illegal group. Afterwards, the strategies of those organizations are applied, and in the context of the government it is decided by the political process. This allows us to gauge the effectiveness that different policies may have on the society as a whole, and on the development of institutions. Preliminary results show that soft policies aimed to convince the agents are more effective than strong policies that affect their income. Furthermore, the model allows to study the strengthening of the democratic process and its interaction with the economic forces in the context of the conflict between a legal and illegal organizations that struggle to control the individual agents.

Keywords

Government, illegal organizations, political institutions, conflict, agent-based modeling, Colombian peace accord, computer simulation.

2 Introduction

The 24 of November of 2016, after more than four years of negotiations with the rebels, a failed referendum that resulted in negotiation with right wing politicians, the Colombian Government and the FARC signed up the "Acuerdo del Teatro Colón". This marked the end of that guerrilla as an armed organization, their entry into democracy, and the start of the post-peace period; a stage in which the written accords should be taken into reality. Structurally, the accords are split into 6 sections: integral agrarian development policy, political participation, end of conflict, solution to the problem of illicit drugs, victims, and accord validation process. By choosing those particular subjects to focus on, both rebels and state agreed on a shared vision of both the causes and the possible paths to solution of the conflict. The list could be rephrased as: strengthening strengthening of economic institutions, the establishment of real political institutions, an end to the violence, a solution to the illicit drug money, broad justice, and validation of the process.

Acemoglu and Robinson, in [AR12], already presented the idea that the solution of the Colombian conflict goes by generating the virtuous cycle of strengthening the economic institutions, creating real democracy, while reducing the de-stabilizing factors. More importantly, in the context of the signed accords, Colombian society faces the challenge on how to achieve this best case scenario be achieved in a timely manner; knowing that failing to do so can end up in a new spiral of violence.

In the present paper we tackle the problem from the computational point of view. We propose an Agent Based Model (ABM) that, in our view, summarizes the main characteristics of the system; while giving the advantage of being able to simulate different ranges of parameters in a safe controlled environment. In Section 3 we present some literature results that guide the model description and ranges of parameters. In Section 4 we present our ABM. Section 6 discusses the main results of the model. And finally, in Section 7 we present the concluding remarks and propose future paths that can be taken in order to understand more of this issue.

3 Literature Review

3.1 Agent based models

Agent based modeling (ABM) of social conflicts and in particular of armed conflicts against a central authority and civil violence has been the subject of recent research [Eps02, Lem18]. In the field of social simulation ABM has been applied to a wide range of social phenomena. Since the earlier studies of segregation by Schelling [Sch71], to contemporary research of opinion dynamics [XWX11] and worker protest [KH11] ABM has shed light to the understanding of social behavior from a bottom-up approach. The evolution of this subfield of ABM can be tracked in the outstanding trilogy coauthored by of J. M. Epstein [EAP96, Eps06, Eps14] which is also a very important signal of the impact of modeling and simulation on the social sciences.

In his seminal work on civil violence Epstein [Eps02] introduces an ABM which captures key concepts of modern theories about the origin of conflicts such as relative deprivation in the theory of frustration-aggression of Gurr [Gur15]. The model has two variants of civil violence: (Model I) rebellion against a central authority and (Model II) ethnic violence between two rival groups mediated by a central authority. In the Epstein model there are two types of agents *Cops* and *Citizens*. Depending on both the level of its grievance and perception of risk *Citizens* can become *active* and *Cops* can arrest active *Citizens* inside its vision radius following a probability function. The model predict intermitent large peaks of rebelion which is a signature of large scale civil violence.

Drawing on this ideas Lemos extended the model of Epstein by proposing the following new mechanisms [Lem17]: deprivation-dependent hardship, vanishing of the risk perception below a critical ratio between deterrence and "group support", legitimacy feedback [LLC16], and network influences. With these changes the models were succesfully applied to some conflicts in the *Arab spring*. Other interesting model and implementation is MASON Rebeland [CRR10] which allows for the modeling of different political structures as well as environmental conditions.

The inherent complexity of armed conflicts makes ABM an appealing approach which by extension can be used to study the situation after a peace agreement between the conflicting parts. The aim of this modeling is to provide insight of the underlying mechanisims that would assure a good end to the reincorporation process and the transition of society to a peaceful living. In the colombian case it is of current interest to study how the implementation of the peace agreement can strengthen the state in those zones which were previously under gerrilla control. Among the main economic activities in these territories both coca agriculture and illegal mining are found, therefore once FARC abandoned this lands they were taken by illegal armed groups like narcotraffic cartels, paramilitary groups and criminal gangs. An ugly and inconvenient situation allowed by the weakness of the state in these regions. Rather than aiming at the description of the reincorporation to society of former gerrilla members [MPU18], or modeling the gerrilla war [Dor05], our model is concerned with the dynamics of territory control by the state or by illegal groups in the post-agreement scenario.

Other works worth to mention include :[Mor16], [WFM07], [GII$^+$09], [RLSS06], [JWC11], [L$^+$16], and [MR13].

3.2 Coca growing from the peasant perspective

3.2.1 Why do peasants grow coca?

The literature lists the following reasons: ubiquity of the crop, simpler handling compared to legal crops, higher yield than legal, a secured future market provided by the illegal ruling organizations, absence of transport costs, and existence of a de-facto crop insurance: illegal organizations are willing to pay in case the crop is destroyed by the government (See [Cai15]). At areas that are isolated or that are controlled by illegal organizations coca paste has been used instead of currency, since it had a stable price and was largely available; therefore peasants would grow coca in order to participate of the economy. (see [AG17b], pg. 15).

Illicit crop production does not improve the means of subsistence of peasants ([Cai15] pg. 9 and references therein). Possible reasons are either be due to an increase of costs of living in coca growing regions, and also because the difference in income from legal to illegal not being significantly larger. Illicit crop production just seems to provide a more steady and secured flow of income to peasants than legal crops does.

Peasant income in Colombia

Year	Legal	Illegal	Summary
2012	US $ 935		" El 46,6% de campesinos del país subsiste con 4.450 pesos diarios". 11 Julio 2013. El Colombiano
2016		US$ 960	[uno17]
2017		US $ 1180	"Colombia's coca production soars to the highest level in two decades, US says" 14 March 2017. The Guardian.

3.2.2 Profitability of growing coca

As part of the modeling strategy, we want to compare the profitability of coca leaf against other activities for a peasant. As an example, take Tumaco. Data from the coca cultivation survey, from the Government of Colombia and the United Nations Office on Drugs and Crime (UNODC), is summarized in Table 7. The report from 2017 does not report the population variables (households, families, individuals); probably because of the adjustments that have to be done due to the 2018 Census. For 2016 the average income per capita was 960 US dollars *per person*, with an average of 5 household members involved in coca harvest ([uno17], pg 87); which would give a gross income (this number, does not take into account the production costs), of 4800 US $ per year. One could argue that as this number is an average, then it takes into account those producing the coca paste, which is much more profitable. So let us estimate the household income differently: take the yearly productivity of coca leaf, which is 5600 Kg/ha, multiply by the prize, 0.95 US/Kg, and deduct the agrochemical costs, and finally multiply by the average farm size. This gives 5016 US $ per year.

Table 1: Tumaco household income. [1]

Decile	decile monetary income	yearly income/household
Decile	(COP)	(U$ dollar)
1st	222064.3	888.3
2st	505831.9	2023.7
3st	698061.6	2792.2
4st	849607.8	3398.4
5st	1016071.3	4064.3
6st	1237308.3	4949.2
7st	1519207.9	6076.8
8st	18789182.2	7515.7
9st	2530051.4	10120.2
10st	4739292.7	18957.2
total	15196317.1	6078.5

Both calculations ("5 times average income of one" or "coca leaf production of one average farm"), give a number close to 5000 US $ of income per household per year for coca leaf production in the Tumaco area. To put this into perspective, this would correspond to the 6th decile of income in Tumaco, according to the DANE data shown here in Table1. (A similar calculation gives 5477.12 for the fourth decile in Bogotá). Thus, the question: which is the alternative income that a tumaquian household would earn if they switch from illegality towards legality? Let us mention two possible estimates: the average of those 5 deciles, 2633; as well as its minimum, 888.3.

How many households are there in Tumaco, and how many of them are related to coca growing? The "Encuesta Nacional de Presupuetos de los Hogares ENPH", claims that Tumaco had 30000 households in the 2016-2017 period (which, would give an estimate of 6.9 individuals at each household). In order to compare, we propose the following order of magnitude calculation: DANE reports a population for Nariño of 1787545 for 2017 and 493561 households. Tumaco had 208318 individuals, so if the household size is the same, the proportion of households would impute 57519.

The survey does not state the number of households involved in Coca growing, but an estimate from the newscast "90 minutos" of Pasto, gives the number of 19000 households for 2016 (although the same news report also mentions 19 000 individuals). This would give an average land of 1.22 ha per household, which is close to the national average farm size of 0.96 ha. Take into account that these are just averages. It does not mean that the most common household involved in coca growing has an income of 5000 US dollars a year, only that this is the average.

3.2.3 Coca transformation by peasants

In previous years, some peasants used to perform the first stage of the transformation process from coca leaves to coca paste. Mejía et. al. claim that two-thirds of them did it. The same authors claim that now the proportion of peasants that produce paste has fallen to about 35%, due to specialization of middlemen in the transformation process and growing costs. [DM15]

3.2.4 Where is coca grown?

UNODC and the Government of Colombia publish periodically the Coca Cultivation Survey. Their document from August 2019 presents data from 2018. The trend, in recent years, has been of increasing the cultivated area; while at the same time reducing the number of municipalities that are being affected. In 2018 there is a small decrease in area of 1.2%. The figure [Fig. 1] shows the density of areas that where coca is being grown. The highest density occurs in areas close to the border, in the departments of Nariño and Norte de Santander. Figure [Fig. 2] historical changes in coca production in the period 2009 to 2018. In green are areas that have abandoned production, in red areas that permanently affected in the time frame, in orange areas that have been recently affected, and in pale pink areas that have been sporadically affected. It is interesting to compare both maps with [Fig. 3], in which the territories affected by FARC are depicted. We see both regions in which FARC was active and coca growth has diminished, as Vichada, Arauca and Meta; as well as zones under FARC influence in which there has been an increase in coca growth: Norte de Santander, Nariño, and Putumayo. However, since those later correspond to border areas as well, one might be inclined to think that FARC profited from the ilegal coca growth that was happening there anyways, rather than forcing the population to grow the crop. One opportunity in which the legal institutions could profit from the peace accords is the sharing of information that could lead to dismanteling of the narco in regions in which FARC has demovilized. Clearly this is lacking from the implementation of the peace pact.

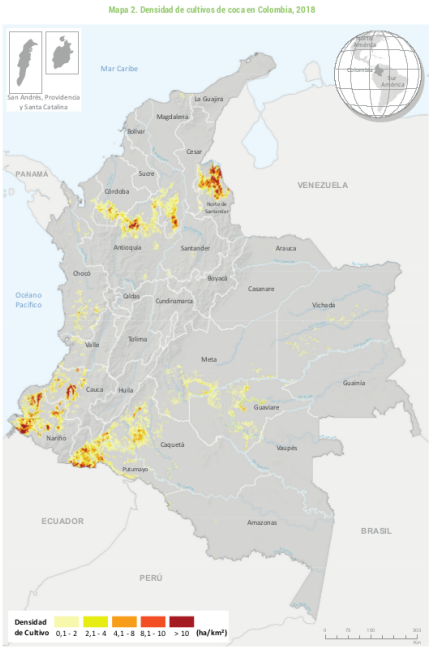


Figure 1: Density of Coca Cultivation, 2018. Taken from [uno19].

3.2.5 Cost of eradication strategies

The next question is : what is the cost of one eradication operation? There seems to be a lack of micro-data in the military government public finances, probably due to security reasons. Thus, we use the numbers in table 3 to make an estimate.

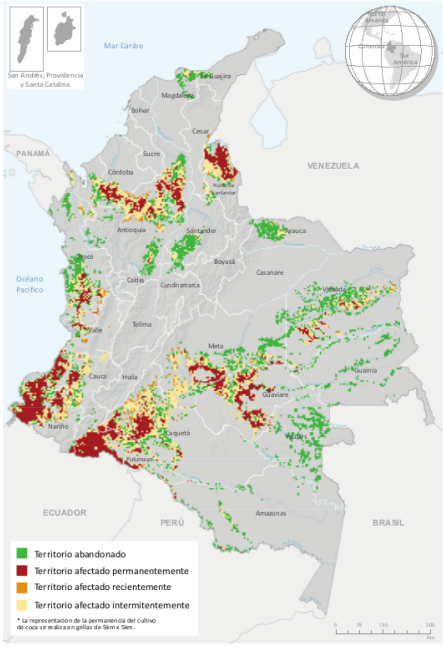


Figure 2: Changes in Coca Growth in the last 10 years. Taken from [uno19].

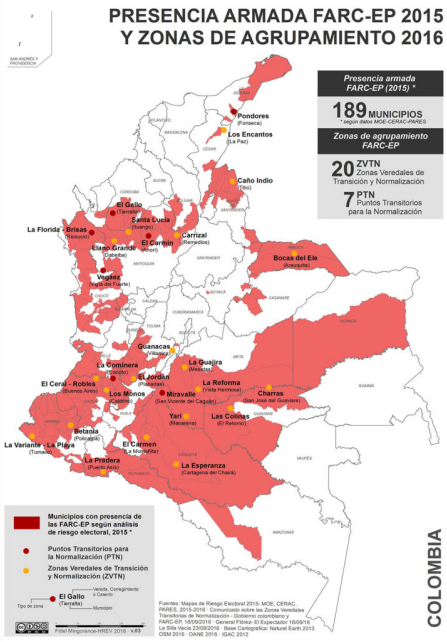


Figure 3: Historical zones of FARC and localization of the “Transition and Normalization Peasant Zones”. Colombia Plural.

Table 2: Model constants

name	value	Unit
Monetary	1000	US Dollars
Time	2	Months

Table 3: Military expenditures 2017

name	value	Unit
1 hour tucano flight time	$450 - 500$	US dollars
1 hour P Hawk helicopter flight time	24475	US dollars
1 month salary soldier	1400000	COP

A crew of 5 soldiers, plus half an hour of tucano flight, plus 1/10 th of Helicopter flight (assuming 1 helicopter is needed every 10 flights to persuade attacks on the plane), gives 2810 US dollars. This is in line with the cost proposed by Mejía et. al. for spraying 1 ha.

We use the constants as in Table 2.

3.2.6 The coca, coca paste and cocaine market within Colombia

The coca market has been categorized as a monopsony, in which the illegal organization that rules the territory is the single buyer for the coca leaves and coca paste, [DM15]. The same authors claim that intermediaries between peasants and cartels receive about 300 million US $, slightly more than peasants; their added value being the processing from coca leaf or coca paste into cocaine clorhydrate.

3.3 Government policies to curve production

3.3.1 What is the relative size of coca business?

In 2018, UNODC estimates the total production of coca leaves in Colombia to be 977400 metric tons. At a price of 2250 COP/kg, (0.76 U$ / kg), this gives 2199 thousand million pesos. This, however, corresponds to an small fraction of the income. Revenue out of the illicit drug sales at United States could be between 10 and 24 times as much as that, as estimates for 2012 range the revenue to the US from cocaine between 3578 s and 8492 million US dollars, while the farm price was 370 million dollars. As comparison, the general budget of Colombia awarded for "Defense and Police" on 2017 the sum of 29470 thousand million pesos, about 10513 million US dollars. It would seem that a better strategy to end the illegal coca business would be to just buy the whole production on the farm, rather than spending money on the military task of destroying it.

3.3.2 Forced eradication

Aerial forced eradication is a costly, inefficient operation. Mejia et. al. estimate that between 15.4 and 50 hectares have to be aerially sprayed in order to eradicate 1 hectare. This means that the cost of aerial eradication ranges between 37000

Table 4: Coca and cocaine value

Year	Total value at farm	Total value at US	Summary
2012	US $ 370 Million	US $ 3578 to 8494 Million	[uno13] [Fer]
2016	US$ 960 Million		[uno17]

and 120000 US$ per hectare in 2014. To put this into some perspective, the UNODC calculates an average income per peasant per year of US$ 960. Besides, as Mejia et. al. claims:

"Many observers have argued that the main result of the campaigns to eradicate illegal crops is to displace the crops, not to permanently eliminate them." [AG17a]

A model from Mejía et. al., reported in [AG17a] produces the numerical constants presented in the Table 5.

To shed some light into the Cocaine elasticity price of demand, Andreyeva et. al. reports the elasticity of "food away from home" in -0.81, "Cereals" in -0.60, "Milk" in -0.59, and "Eggs" at -0.27. [AT10].

3.3.3 Model Constants

The model constants are included in Table 6.

Table 5: War on Drugs parameters and estimatives, from [AG17a], between 2000 and 2008.

Value	Summary
55 cents US $	Colombian government net cost per dollar producers receive.
2 cents US $	Colombian government net cost per dollar trafficers.
0.22	Relative importance of land vs chemical precursors labs and manpower in cocaine production.
0.78	Relative importance of routes against cocaine itself on the ilicit cocaine trafficking business.
US $ 163000	marginal cost to US of reducing 1 kilo of transacted cocaine by attacking production
US $ 3600	marginal cost to US of reducing 1 kilo of transacted cocaine by attacking trafficking
0.007 %	decrece in cocaine transacted in global markets given a 1% increase in the US millitary aid fighting production.
0.3 %	decrece in cocaine transacted in global markets given a 1% increase in the US millitary aid on controlling routes of trafficking.
4:1	Relative efficiency of Colombian government against traffickers in the fight for control of narcotics routes.
1:3	Relative efficiency of Colombian government against traffickers in the fight for control of the territory.
0.8 %	Productivity increment of ilegal groups (cocaine? coca?) given a 1% reduction in land control
0.1 %	Productivity increment of remaining traffic routes (cocaine? coca?) given a 1% reduction route control
-0.6	Elasticity price of demand, a increase of 1% in price produces a fall of 0.6% in wholesale market sales

Table 6: Model Constants

Name	Symbol	Value
timestep	`i`	1 click = 2 months
agent vs. people		1 agent = xxx people
money	`dprod0`	1 = xxx USD

Table 7: Coca cultivation surveys

Characteristic	Year	Value
Net Area	2016	146000 ha
Net Area	2017	171000 ha
Households involved	2016	106900
Annual average income per capita	2016	U$ 960
Average farm size	2016	0.96 ha
Average farm size	2017	0.96 ha
Tumaco	2017	19517 ha
Tumaco	2016	23148 ha
Fresh coca leaf	2015	1.09 US $ /Kg
Fresh coca leaf	2016	0.95 US $ /Kg[uno17]
Yearly agrochemical costs	2016	494600 COP/ha (95 ± 5)USD
Yearly productivity coca leafs	2016	5600 Kg/ha

4 Model

There are different types of agents. First type of agent is the **household**, which represents both a farmer along with his/her patch of land. The set of all households, represents the territory where the conflict takes place. Household attributes are:

index an integer variable, i.

location a vector giving its coordinates over a grid

use integer variable. For *legal* cultivation takes the value $u(i) = 1$, $u(i) = -1$ for *illegal* cultivation.

Capital that has been accrued by the household, over previous economic cycles. $k(i)$

production a real number which represents the amount of money that comes out of the household. It depends on the capital accrued by the household, and the services and facilities that are provided by the state/para-state. It does not depend on the kind of crop that is produced (since, as we see in the literature review, zones with larger illegal income have inflation and thus real acquisitive power does not change, also income of illegal households is similar to that of income of legal households). Production by household i at time t is $p(i,t)$

The production by a household under legal or illegal production is given by:

$$p(i,t) = i_0 \cdot \overbrace{\left(\alpha_{KO} - (\alpha_{KO} - 1)e^{-\beta K_O(i)}\right)}^{\text{org. capital multp.}}$$

where α_{ki} is the maximum productivity multiplier given by capital of a household (understanding capital as tools, machinery as well as soil stored nutrients, etc), α_{KO} is the maximum productivity multiplier to the household given the capital that the ruling organization has invested in productivity improvements (roads, irrigation systems, commercialization policies, a fair legal system, etc; see "capital invested in productivity", in the description of ruling org, below.). Both individual and organization capital multiplier functions are monotonous increasing asymptotic exponential functions. An example is given in the figure [Fig. 4]. β can be thought as units of capital, how strongly capital affects the individual.

tax a real number that represents the amount of money taken by the ruling organization.

state

$$t(i,t) = t_0$$

insurgency

$$t(i,t) = t_0 \cdot m_{ti}$$

m_{ti} is a multiplier indicating that the insurgents tax rate is different (larger or smaller) than that of the government.

subsistence threshold Amount of money that is needed in order to maintain the household under the control of a given ruling organization. Represents the money that will need the householder to pay for her/his subsistence needs, leisure, etc.

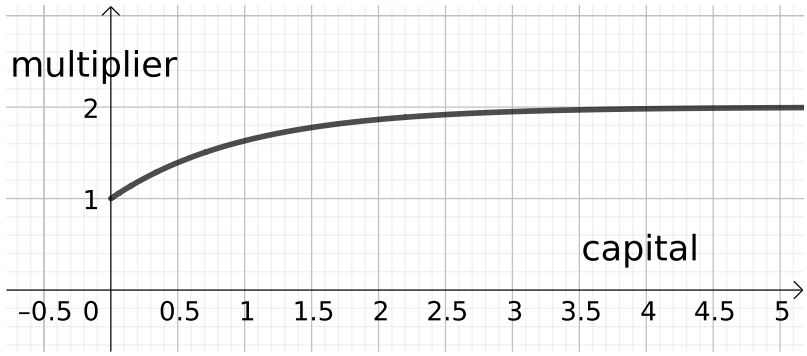


Figure 4: Productivity multiplier, with $\alpha = 2$.

calmness/unrest Real variable that represents how content the agent is with the current state of affairs. Is calculated as:

$$c(i,t) = c_{\text{residual}} + c_{\text{income}} + c_{\text{neighbors}}$$

with: c_{residual} a fraction of the value that c had the previous step, c_{income} is proportional to the income, and finally $c_{\text{neighbors}}$ is proportional to the number of neighbors that adhere to the same ruling organization. Explicitly:

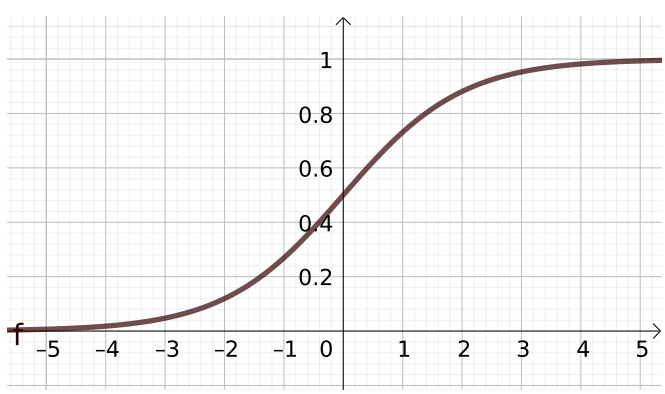
$$c_{\text{residual}}(i,t) = r_r \cdot c(i,t-1) \tag{1}$$

$$c_{\text{income}} = r_i \cdot (p(i,t) - t(i,t)) \tag{2}$$

$$c_{\text{neighbors}} = r_n \sum_{z \in \text{neigh}(c)} u(i) \cdot u(z) \tag{3}$$

Given a value of c, the likelihood that the household stays in the current political system switch is given by:

$$p_s(c) = \frac{e^c}{e^c + 1}$$



Future modification: to include a term proportional to the distance to the geographical center of mass of the ruling organization.

Secondly we have the **ruling organization**, whose attributes are:

kind it is either the *state*, or the *insurgency*

control area set of households that adhere to it.

gross income amount of money that is collected from the households by means of taxation.

capital invested in army how much money has the ruling org set up for its efforts to fight other ruling organizations.

capital invested in productivity how much money has the ruling org set away to improve the productivity of the households under its control. For example, methods to transport the crops (airplanes, roads, trucks), irrigation systems, crop insurance, facilities to increase the crop value (as food processing systems, or laboratories to crystallize), etc.

ratio of income invested in productivity against cohersion fraction of the income that is invested every cycle provide services and facilities that lead to the efficient production by the territory, represents roads, vehicles, irrigation systems, etc; the rest being used to build an army/police that enforces the taxation system. *This affects the possibility of having different policies: militaristic or social.*

political system it can be either *inclusive* or *exclusive* political institutions. Under the former, the total amount of money that is received from taxes will be used in productivity amenities, increasing the productivity of the land. In the latter, there is a function that defines how much is invested and how much is loss to corruption. [2] *A future modification of the model can include elections.*

Algorithm:

4.1 System set-up

Household control, amount of initial capital, is defined. This is done once.

The next steps would be included in a loop.

4.2 Production step

Each household calculates its production.

4.3 Taxation step

Households are taxed by their ruling organization.

4.4 Household control decision step

Given the net income, a rule is applied to decide whether the households continue or change its ruling organization.

[2] It can be a proportion of the income or a decreasing function; the former represents corruption that does not disrupt the functioning of the state and accumulation of capital (Odebrecht and Reficar being examples: although money was pocketed, something got built), the later represents total coptation of the state by a single leader (Haiti).

4.5 Capital improvement step

The ruling organization decides whether to improve their controlled territory investing its wealth into capital or not. This step could happen with a different frequency, which would represent the difference in timescales between production and capital investment.

4.6 Calculation of macroscopic observables

Total wealth of ruling organizations, total happiness of the citizens, etc.

4.7 End of simulation

After the steps are repeated a fixed number of times, or a global state of the system is reached, simulation stops.

5 Test

The first set of tests were run among two states. This is the net production rule is the same for both ruling organizations.

5.1 Neighbor influence non pbc

As a first test, have created a square grid of $40x40$ households. The color of each household represents which ruling organization has it under control.

The neighbors are the eight closest households, without periodic boundary conditions.

To check the influence of the strength of the interaction over neighbors, we rendered both residual and income calm irrelevant by taking the corresponding fractions as zero, and changed the value of r_n. The figures show the final state of the system, after a fixed number of 100 steps [Fig. 5]. Since the value of r_n in increased the number of contiguous households that belong to the same organization increases constantly.

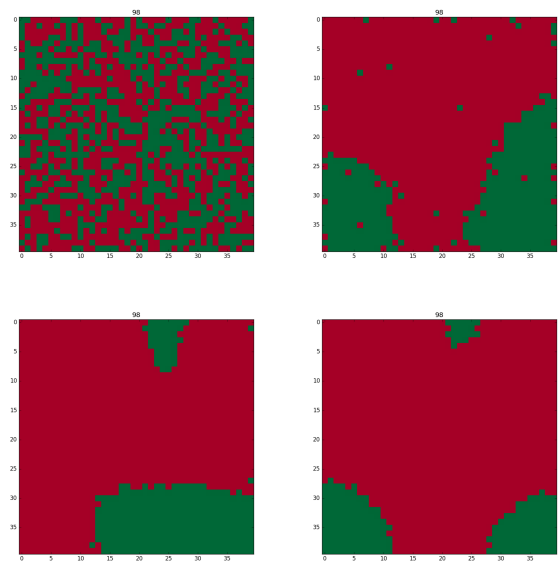


Figure 5: $r_n = 0.2$, $r_n = 0.5$, $r_n = 1$,$r_n = 2$

For $r_n = 0.2$ households flip from one crop to the other randomly. As r_n is increased, households tend to behave as their neighbors, in a homogenization process.

5.2 Neighbor influence with pbc

As a first test, have created a square grid of $40x40$ households. The color of each household represents which ruling organization has it under control.

As the previous section but with periodic boundary conditions, in [Fig. 6]. The pbc cause the system to relax faster, as boundaries are removed.

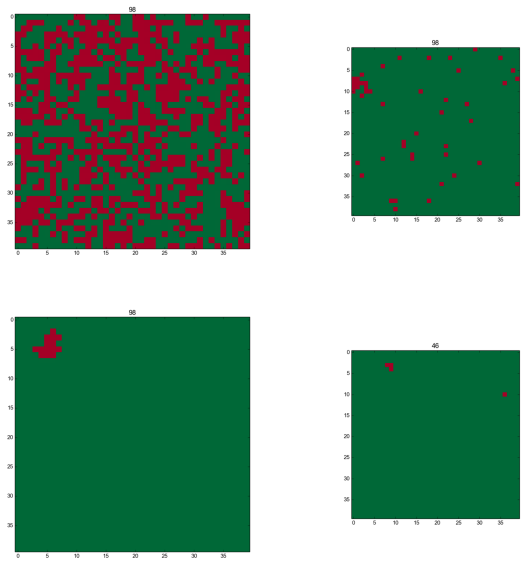


Figure 6: $r_n = 0.2$,$r_n = 0.5$,$r_n = 1$,$r_n = 2.0$

5.3 Symmetry test

As a first test, have created a square grid of $40x40$ households. The color of each household represents which ruling organization has it under control.

Afterward, we tested the simulation varying r_n for an initial distribution of cells in which half align with the government and half with the rebels. Figure [Fig. 7] in the upper row has the state of the system for $r_n = 0.2$, at the left for 1 step, at the right for 100 steps. At the bottom we have the state of the system after 100 steps for $r_n = 0.5$ (left) and $r_n = 1.0$ (right).

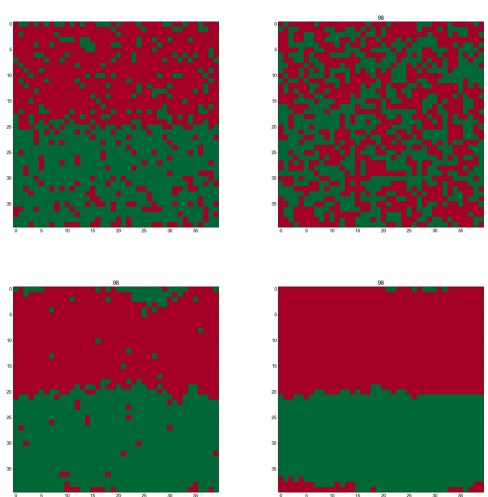


Figure 7: Symmetry test

Next, we created a grid of $100x1000$ households, with a random initial condition. This simulation was run for 10000 steps. Here we measured the average calm of the whole system as well as the number of households that belong to the government. The average calm seems to be a monotonic increasing function of the time [Fig. 8], while the average number of households for the government fluctuates around 6200 households [Fig. 9](in this case half of the households would be 7000, be wary of the vertical axis of this plot). Video.

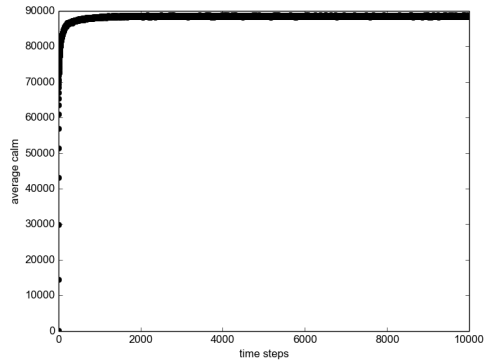


Figure 8: average calm

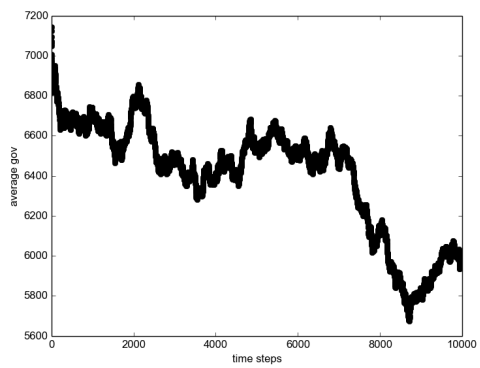


Figure 9: average government

After only 100 steps the system has already reached an equilibrium, as can be seen from the figure: [Fig. 10], in which we placed the final condition 4 times in a grid, to make the pbc more clear.

5.4 Common states

Most common asymptotic states of the system are:

1. Transient state: circular distribution of one group inside a sea of the other
2. Transient state: Mixed blobs of both groups (as seen in [Fig. 10])
3. Asymptotic state: Homogeneous in one side

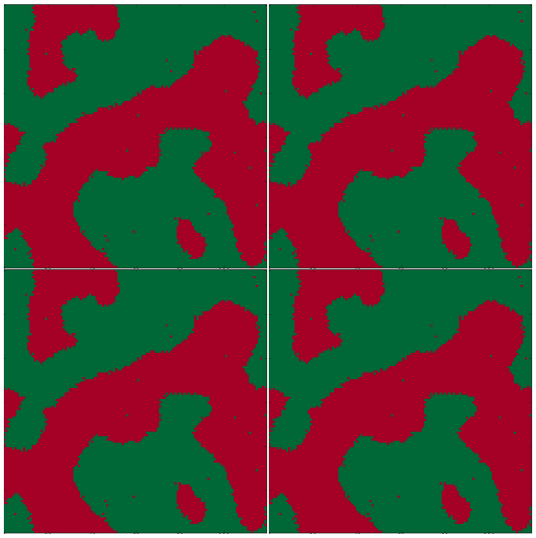


Figure 10: 1000 steps, of a system $100x100$, placed in a panel to highlight the pbc.

4. Asymptotic state: Straight strip of one group surrounded by a straight strip of the other group.

6 Results

The implementation of the model that we discuss in this paper corresponds to the situation in Tumaco. This is a very poor municipality located at the south of Colombia, close to the border with Ecuador. Political differences between the governments of Rafael Correa and Álvaro Uribe, in the first decade of 2000, gave an special legal status to the border municipalities in Colombia; prohibiting the forced eradication with gliphosate (brand name RoudUp). Besides this, Tumaco suffers from high indices of extreme poverty, high income inequality, violence, corruption, and an endemic problem with coca crops.

Table 8: Population.

	Year	Value
Tumaco	2017 (estimated)	208318 individuals
Nariño	2017 (estimated)	1787545 individuals
Nariño	2017 (estimated)	493561 households[3]
Tumaco	2017 (imputed)	57519 households[4]
Tumaco	2017 (estimated)	30000 households[5]

For the population, we used the estimate the 2017 Tumaco population from DANE, in Table 6; income from Table 1. For our simulation, we set up the households in a square array of size $L = 75$, giving 5625 Agents. We chose the maximum multiplier of productivity to be equal to 2 for government, and no multiplier for the Coca crops.

6.1 Initial Conditions

For the model to better resemble the real system, the initial conditions have to be carefully chosen. For each agent-household we choose the income according to the statistical information given by DANE, as in Fig.11. Remember that in our model the adjacent cells correspond to "close" neighbors, in a social sense -not necessarily geographical-. There are periodic boundary conditions in left and right.

The initial households with coca are chosen randomly but strongly correlated with the income Fig.12.

From this onward the dynamics follows what has been described before. Consecutive election cycles define the policies according to different strategies.

6.2 Spending strategies

In this set of simulations we allow the voters to decide the percentage of the government money that is spent either on eradication, with voluntary eradication strategy, or on increasing the productivity. The percentages are set as the fraction of the votes of the most recent election.

We propose to confront two extreme situations, either there is an initial consensus for eradication or there is for increase in productivity. This can be interpreted in different ways, for instance, it could be the change between a "winner takes all" in which previous governments would choose a single policy, and a more nuanced government in which the government splits the income in a more nuanced way. Fig. 13 shows the result of 6 consecutive elections. In this simulations we

Figure 11: Legal income (internal units in which 1=500 USD/month)

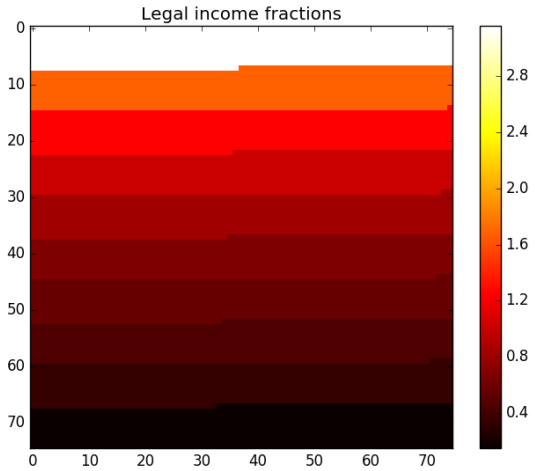
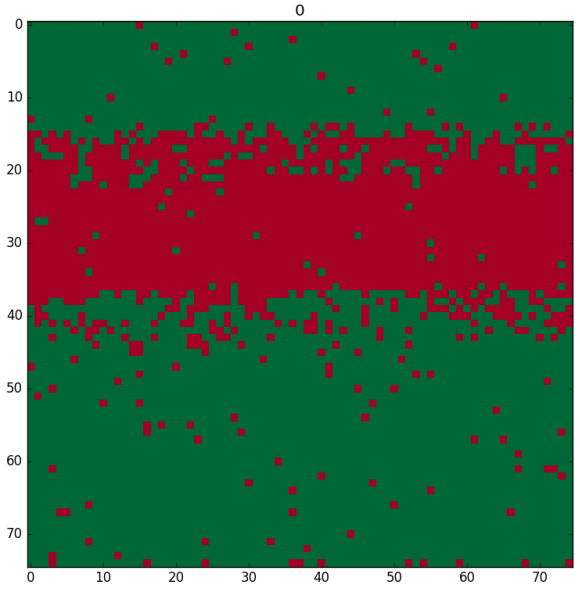


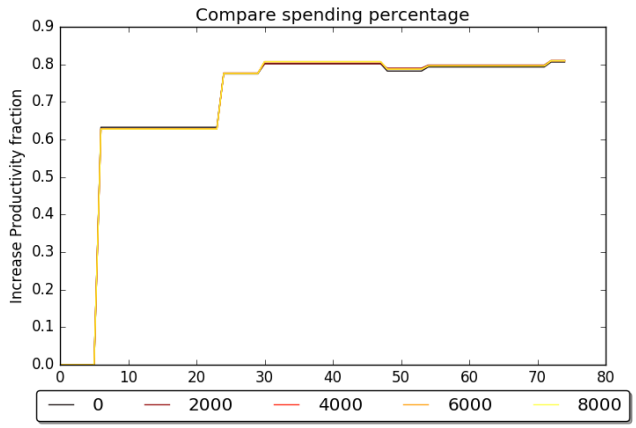
Figure 12: Initial distribution of households with coca (red) and without (green)



change an external amount of money (say central government transfer), that is spend in eradication on top of the local government budget. As result of the first election the fraction spent in productivity jumps from 0 to more than 60%, and continues at this level ever since.

Other way to see this trend is to check at the vote fractions. For simplicity, set the central transfer to 0. An interesting situation can be spotted in Fig. 14, in which in the first electoral cycle the households change drastically to increase their productivity. This is caused by having a larger negative slope fraction in the first voting cycle, and the contrary in further votes. Now, we can interpret this change in public attitude as a hallmark of a virtuous cycle, since increments in

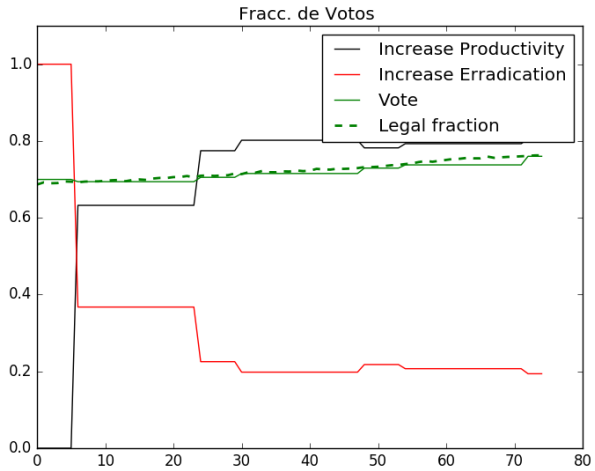
Figure 13: Spending percentages. Color corresponds to a fixed extra income spent in erradication.



productivity could foster more democracy as well.

To check that this is not an artifact of the initial conditions, we ran the experiments with the opposite situation, in which initially there is a concensus on sending all the local budget into eradication. In this case, some of the voters switch, but not the largest share of them, see Fig. 16. Therefore it is clear from this simulations that the democratic process, in this case, gives more value to productivity over eradication.

Figure 14: Voting fractions. Initially there was concensus for erradication. Red, vote for increase in erradication; black, for increase in productivity. In green the fraction of votes.



Other aspect that can be acknowledged from this simulations is the fraction of the households with coca (HWC). Both in 16 as well as in 14, even though the central government transference is zero and the local government spends most of its share in productivity, there is a decrease in the number of HWC. This suggest that, at this particular set of parameters at least, an idle illegal organization would slowly reduce their grip on the population. Therefore, from their point of view,

Figure 15: Slope fractions. Green, positive; red, negative.

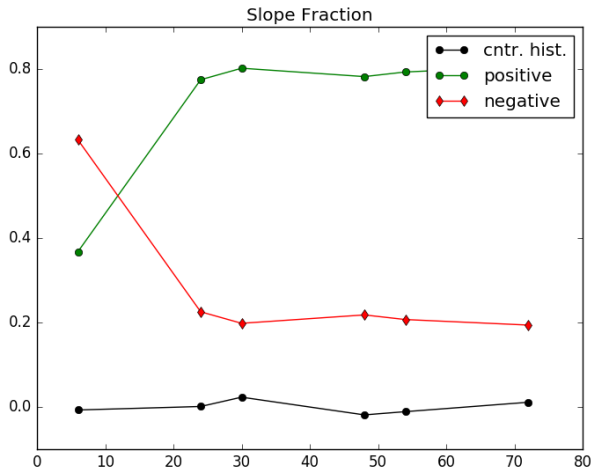
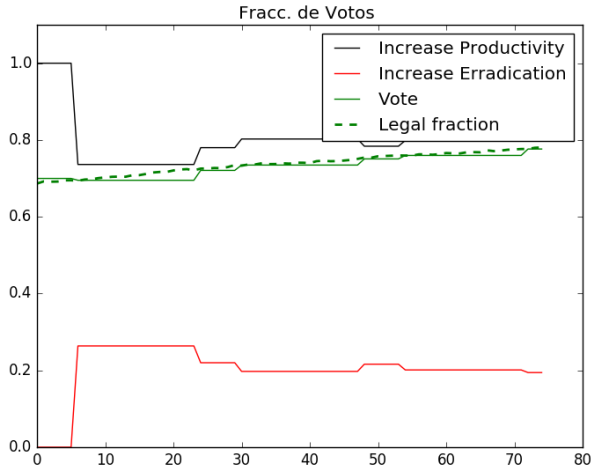


Figure 16: Voting fractions. Initially there was concensus for productivity increments. Red, vote for increase in erradication; black, for increase in productivity. In green the fraction of votes.

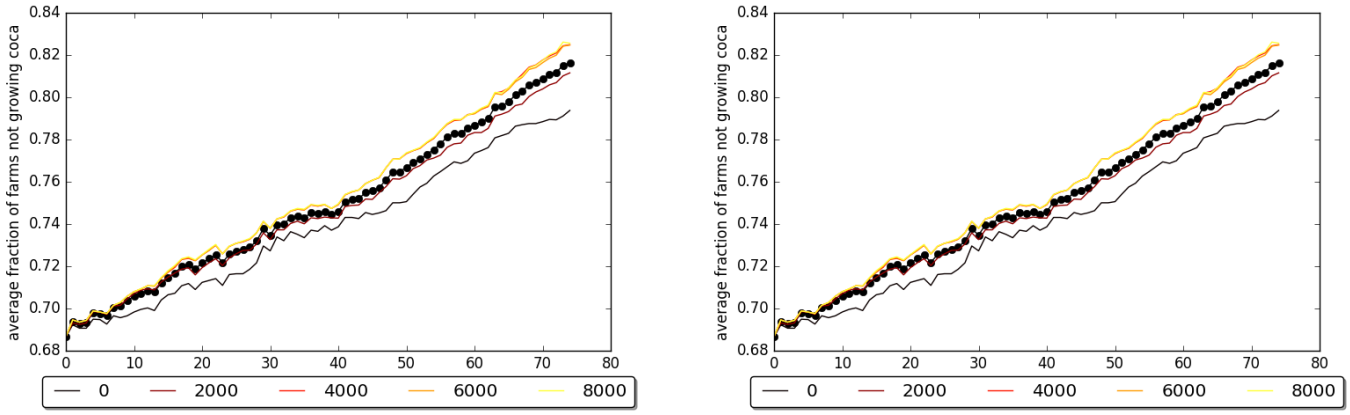


there is a need to force households to grow coca.

6.3 Eradication strategies

Now, under different circumstances it is possible that a different argument arises in the democratic process, one scenario in which voters decide on the type of eradication strategy what is undertaken. Here we proposed basically two strategies, one that simulates forced eradication and one that does voluntary eradication. In both scenarios we also choose to decide whether households are with coca with the same probabilistic argument that was described earlier. In Fig.6.3 we have the households without coca. At the left we have the voluntary eradication, while at the right the forced eradication. Notice how the axis have different scales, therefore it can be said that voluntary eradication is a better strategy than forced eradication.

Figure 17: Fraction of households without Coca. Left, voluntary eradication; right, forced eradication.

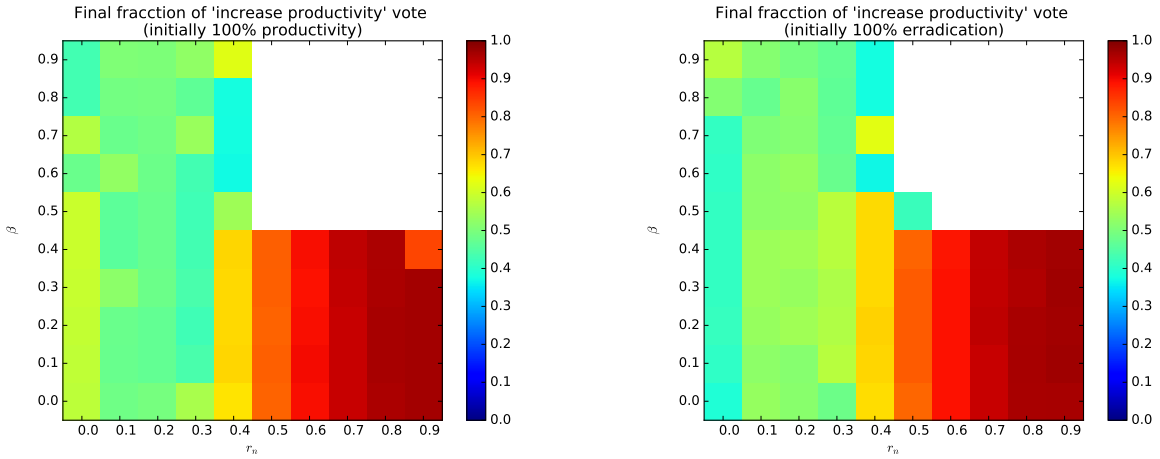


6.4 Parameter space

In this section we study the behavior of the model while changing different parameters of the system; which results in a comprehensive view of the behavior of the system. This exploration not only gives a deeper understanding of the model itself, it also serves the purpose of a consistency check.

In this case we will be comparing the eradication strategy against the increment in productivity, as previously discussed. Firstly, we took the eradication concensus, and ran simulations changing the values of the parameters β, which represents the strength of the organization capital in the increment of calm, and for each of those values we also changed r_n, the value of calm given by each household-neighbor pair.

Figure 18: Final fraction of votes, comparing spending fractions. Left, initial vote for increase productivity. Right, initial vote for increase in eradication



In the left we have the situation in which the concensus goes for an increase in productivity. The left-hand half of this represents values of $r_n < 0.5$. Here we see mostly greens and yellows, which means a support for an increase in productivity between 0.5 and 0.7; thus it is still larger than the half. As r_n grows, for low β, the fraction increases to values closer to 1. Thus, a large social cohesion galvanizes support for productivity. At the right panel we have the situation in which the initial concensus goes for eradication. Interestingly, broadly the situation is similar. For $r_n < 0.5$, support between 0.4 and 0.7, for productivity. And for low β and large r_n the switch towards productivity is quite strong, as strong as when the initial concensus was to increase productivity. In the upper right we do not include values, as here no policy wins completely over time, on the contrary they swap between one extreme and the other.

Our interpretation of this graph is that in this context the productivity increment is a better policy from the point of view of the voters, irrespective of their initial concensus, even for strong peer pressure values.

7 Conclusions and future work

The present paper studies the effect that different polices may have on the voting that households can have under the economic pressure that comes from different values of income; which in turn come from either growing or not growing coca. The model continues a tradition of agent based models dedicated to social issues, while it presents a novel set of characteristics.

According to our model, the voluntary eradication is more effective than the forced eradication. We also compared different spending strategies, and interestingly found that increments in productivity tend to win over increments of eradication money over a wide set of parameters.

It would be interesting to see whether this can be mapped onto the real social systems, by trying to measure the strength of the social interactions as well as the productivity increments produced by an increase in the capital that governments can invest.

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