Producers and Predators:
An Agent-Based Perspective

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Abstract:

In this paper, we investigate the relative importance of cooperative behavior and environment for economic growth in simulated economies. We consider a simple world populated by individuals who can either utilize resources from their environment or create wealth within interactions with other agents. Each newly created piece of wealth is then divided among agents participating in that particular interaction similarly to the prisoner's dilemma game. Along with the other literature, the cooperative behavior and the ability to enforce cooperation are the key factors for long-term sustainable economic growth in our simulations.

Interestingly, the effect of enforcement and punishment of piracy was not always positive: Introducing such mechanism caused elimination of the most successful agents without the positive effects on cooperation and productive economic activities. Hence, the income was lower for low enforcement rate than for the economies without any mechanism supporting cooperation. Similar effects occurred in the simulations of institutional change. In case of a discontinuous change, a radical enforcement mechanism was implemented in one point of time and it caused a sharp fall of wealth. Nevertheless, after some time the positive effects of cooperation dominated and economic growth emerged. As far as gradual approach to an institutional change concerns, steady stagnation instead of sharp fall was generated and the recovery was slower, too.

Keywords: *cooperation, iterated prisoner's dilemma, economic growth, institutional change, agent-based modeling*

JEL Classification: D70, K42, O12, Z13

1. Introduction

Persisting cross-country differences in economic performance are still challenging for theories of economic development. Traditionally, there was an implicit assumption that all countries have the same growth trajectories and the only difference between the developed and the underdeveloped countries is in their current stage of economic development[1].

The income gap was, however, not closing but even more widening during the recent decades. Consequently, many researchers started to ask, whether there are not any fundamental differences among the rich and the poor countries that can account for such persistence in the income gap. Following the tradition of the institutional economics, many researchers believe that the key might be in different institutional structures that shapes direction and the form of the economic activity in these countries. For example, D. North (1990) argues, that "it is the inability of societies to develop effective low-cost enforcement of contracts", that caused long-lasting stagnation and the current underdevelopment in many countries[2].

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1 This approach follows the theory of the stages of economic development originated by W.W.Rostow (1960).

2 Recently, the effects of trust and culture of cooperation on economic growth started to be emphasized; other

The underlying hypothesis is as follows. If the enforcement mechanisms are absent or not effective, participation in productive activities "is discouraged by the prospect that anyone engaging in such activities is unlikely to receive its full benefits. Any expropriation of the proceeds of market activity by dishonest parties to a contract, bandits, or corrupt government officials, is therefore likely to reduce incentives and opportunities for production, investment, and innovation" (Dabla-Norris-Freeman, 2004). Gradually, as the share of population involved in productive activities decreases, a different set of abilities and knowledge linked with predatory activities and piracy emerges and spreads in the society[3].

In this paper, we investigate the relative importance of ability to enforce productive behavior and the importance of the environment for economic growth within a simulated economy. Our economies are populated by agents, who need to be engaged in two types of economic activity in order to get some energy to survive. They can either utilize the resources acquired in their environment – they may cultivate land and gather crop, for example. Alternatively, they might be engaged in interactions with other agents representing mutual trade and collective production of goods. These interactions are modeled as a simple prisoner's dilemma game: if both producers cooperate, they will be both better off. But if one or either of them defect (predators), the product is either expropriated or deteriorates owing to high monitoring and enforcement costs that have to be spent if the agents do not trust each other. The learning algorithm is replaced by a simple population dynamics that leads to increasing population of agents with successful strategies.

This very simple setting allows exploring how these simple economies evolve in different environments without the need for optimization, learning strategies based on the knowledge of each agent's payoff and similar assumptions. More specifically, the focus is on the conditions under which economic growth emerges. The conditions of simulations differed in two aspects. Firstly, agents might be able to detect those, who don't cooperate, but defect (the predators), and punish them. It was implemented as an exogenously given possibility of detection here. Secondly, the conditions for utilizing resources from the environment might differ, too. If the environment is very rich on resources, the incentives for other economic activity are much lower, except for the actions directly connected with exploiting them.

Our results show that productive behavior does not prevail in any community without any ability to detect and punish defectors. In this case, the risk of interaction with predators and expropriation is so high that the gain from on production is not sufficient for producers to survive and predators prevail. Furthermore, the possibility of detection of predators is the key variable for sustainable economic growth as populations with prevailing predators are not able to create enough opportunities for interactions. Only if the environment provides so good resources, that the size of the producers' population quickly increases, economic growth is sustainable without any enforcement mechanism, because these producers are able to generate a large number of productive opportunities. These opportunities generate enough wealth to outweigh the losses from frequent interactions with predators.

On the other hand, the effect of enforcement is not always positive: Introducing such mechanism causes elimination of the most successful agents without contemporaneous positive effects on cooperation and productive economic activity. Hence, the income is lower for low enforcement rates than for economies without any mechanism supporting cooperation. Similar effect occurs in the simulations of institutional change. In case of a discontinuous change, a radical enforcement mechanism causes a sharp fall of wealth in a short term. Although in the long term positive effects of cooperation prevail and economic growth emerges, too. These costs of change, however, lower the incentives for change strongly and together with other factors (cognitive

economists are explicitly working with the concept of social capital following the tradition from modern sociology and works by R. Putnam (1995, 2000) or J. Coleman (1988).

3 Empirical studies supporting the view that "Institutions matter" are extensively reviewed in Aron (2000).

limitations, lack of specific knowledge) can make such change unfeasible. As far as gradual approach to institutional change is concerned, a steady stagnation instead of a sharp fall was generated and the recovery was slower, too.

This paper is related to various strands of research. The idea that social infrastructure and institutional set of the economy affect economic performance has been widely discussed by many economists during last two centuries. During last decades the discussion about the effects of institutions on economic performance turned to the question, why countries or communities insist on inferior institutional set causing lower income. D. North (1990) explained the problem of switch of institutional path to another one using a parallel with technological change. Following his perspective, there are increasing returns in institutions arising from specialization and accumulation of knowledge that make the switch from predatory behavior costly and unattractive. K. Murphy, A. Shleifer and R. Vishny (1991, 1993) and D. Acemoglu (1992) emphasize that predatory activities like rent seeking simply rewards talent through making effort, more than entrepreneurship and production does. If this material attractiveness of piracy and rent-seeking is not limited by social institutions, causes that more talented individuals choose to be predators more likely than producers and, again, increasing returns arise.

Generally, the problem can be interpreted as a system with two possible types of equilibrium. Some of them are represented by culture of cooperation and trust, where production prevails. On the other hand predators are more rewarded in the second group, where piracy dominates to different types of economic activities. Existence of multiple equilibria allows discussing different outcomes of different societies within the framework of general equilibrium. For example, D. Acemoglu (1995) generated poverty traps using this approach. Similar results to previous studies were obtained in series of articles by M. Kim and H. Grossman (1995, 1998 and 2002). More recently H. Grossman (2002) published an interesting extension with central authority that enforces the rules. He showed that existence of such authority is beneficial for both predators and producers, because it protects property of both, thus also property of predators against other predators. H. Mehlum et al. (2003) showed that for the poor countries from the predators club the only possibility how to escape to the high-income producers club is an existence of massive inflow of the new entrepreneurs that might outweigh the effect of old predators.

Furthermore, E. Dabla-Norris and S. Freeman (2004) made an effort to develop a model in which the enforcement ability was endogenous, determined by the share of predators and producers in the society. They showed that in this case identical initial conditions might lead to both equilibria with and without high production. N. Nuun (2005) used these ideas for formulation of a sequential game that helped him to explain the underdevelopment of current Africa. According to his paper, the current income is shaped by the nature of the colonizer and his institutions. If the colonizer decides to extract all the wealth from colonies to his home country, the investment opportunities will be lost for domestic population, and in the second stage underdevelopment occurs. A. Wilhite (2006) applied the methods of the agent-based computational economics to study different forms of protection against predators. Most recently, J. Amegashie (2008) studied the effects of redistribution in economies, where the poor population might behave as predators, if the income distribution is highly unequal. His findings show that if any central authority is able to enforce redistribution, it also might help to assure enforcement of property rights.

This paper is organized as follows. Section 2 shows how the interaction among cooperative and non-cooperative agents might be modeled using a formal static model. Section 3 introduces the implementation within a framework of a multiagent system. The next section presents our results. Finally, concluding remarks close the paper in section 5.

2. A Simple Model of Predators, Producers and the Effects of Protection

In this section we present the main ideas of the static model of producers, predators and protection which can generate multiple equilibria and thus explain some aspects of underdevelopment. The model presented here follows the version proposed by Romer (2001), more elaborated versions can be found in Acemoglu (1995) or in Mehlum et al. (2003).

Consider an economy populated by a number of individuals, who can behave either like producers or like predators. Predators are oriented on various activities from theft to rent-seeking. In fact they try to attempt the output of others and their economic activity does not increase the overall welfare. Next, the producers invest their resources into production and protection of the product against predators so that marginal product of a unit of resources invested into both actions equals. Individuals of both types try to maximize their welfare. Therefore, in optimum, the rewards to individuals of both strategies tend to be the same.

For simplicity assume that each individual is endowed with one unit of time and the production function transforms this one unit of time to one unit of production. Let f represents the fraction of the time that is allocated for protection. Thus each unit of time the produced output equals to (1-f).

However, the predators cause that some part of the output, L, is lost each period. The size of the loss depends on f and on the share of predators in the population R. The total loss of the producers can be then expressed as

$$(1-R)(1-f)L(f,R) \ , \qquad 2.1$$

where $L(f,R)$ is the loss function. The payoff of each individual producer equals to

$$[1-L(f,R)](1-f) \qquad 2.2$$

and this payoff 2.2 is maximized in f given the expected fraction of predators R.

There are several assumptions about the loss function in this model. First, the loss is increasing in R: $L_R(.)>0$; and decreasing in f: $L_f(.)<0$. Thus higher number of predators causes higher loss, but that loss can be lowered by some spending on protection. Naturally, if there are no rent-seekers, nothing is lost. Furthermore the returns in expenditures on protection are decreasing and the loss function $L(f,R)$ is non-increasing in R if the level of protection f is given. Therefore, the payoff for individual predator 2.3 is decreasing if predatory behavior spreads among members of the society.

$$(1-R)(1-f)L(f,R)/R \qquad 2.3$$

In optimum, none of the groups has a higher payoff than the other. Thus, expressions 2.2 and 2.3 should equal. That is,

$$[1-L(f(R),R)][1-f(R)]=\frac{1-R}{R}[1-f(R)]L(f(R),R) \ . \qquad 2.4$$

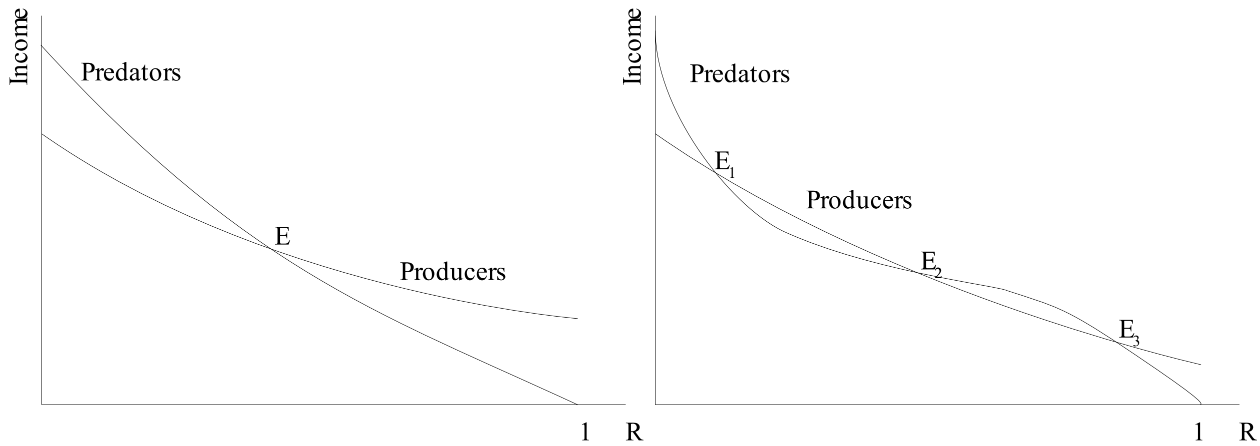
Assumptions about the loss function imply that producers' income (associated with the left-hand side of 2.4) is decreasing in fraction of non-cooperative predators R. This is because of a rise of the rent-seekers' population. It then causes producers to lose more of their income[4]. The predators' income, the right-hand side of 2.4, falls in R as well. Given our assumptions, the fraction of income the predators increases less than proportionally with the rise of R. Furthermore, the increase of R induces the rise of f, hence higher protection costs cause lowering of the overall output, that can be divided between these two groups. Finally, if R = 1, the overall product is 0 as there is no one devoting its time to production.

Illustration of the situation is given by Figure 2.1. It shows how the income of each producer and of each predator changes with the changes in the proportion of predators. The first case shows

4 Romer (2001) derives these statements formally without the need for any specific formulation of the loss function, Acemoglu (1995) and similarly Mehlum et al. (2003) give more elaborated examples.

the situation with one equilibrium level *E* of *R* at which the returns of both types of behavior would equal. The predator's line implies that at the beginning, when very few predators are present, their income is very high. This is because the protection costs are low and the stolen part of the product is divided among lower number of agents. As *R* increases, the individual predator is getting lower and lower income up to the situation, at which there are no product to be prayed.

Figure 2.1: Producers' and Predators' Incomes



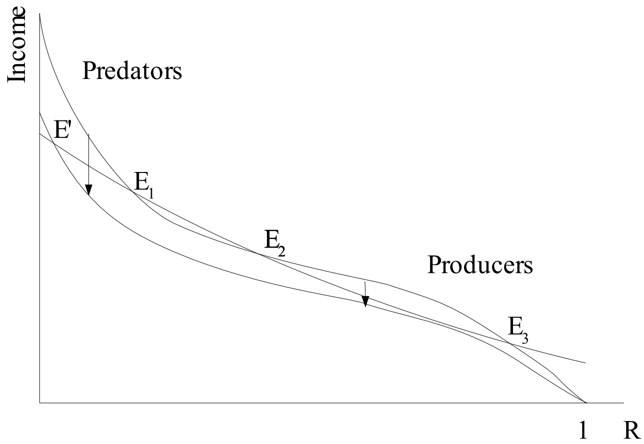
The second plot corresponds to the situation, at which multiple equilibria arise. Formally, this situation corresponds to a loss function that will increase sharply when first predators occurred but then the marginal increases of loss diminish. The three intersections between the two curves correspond to one highly productive equilibrium (E_1), where the loss caused by predators is relatively low, and inferior, “unproductive” ones (E_2, E_3). At those two points, the return of production is too low and many individuals choose to engage in unproductive activities rather than in production. Regarding the stability of each equilibrium, it is evident that the productive equilibrium will be stable. If the fraction *R* is smaller than at the equilibrium, the predators will have a higher average income than producers and their population will rise up to the equilibrium, because after predators' payoffs are smaller than the producers' payoffs. The second equilibrium is unstable: if *R* is smaller, the population tends to the productive equilibrium, because producers get higher payoff than predators. However, if the *R* exceeds the value corresponding to the second equilibrium, it converges to the inferior one with the lowest income because the attractiveness of the rent-seeking activities is again higher comparing to the production.[5]

As a matter of fact, if the case with multiple equilibria is considered this model generates poverty traps because of its self-reinforcing mechanisms: increased number of predators makes production less attractive and causes further increase of predators. Moreover, high proportion of predators makes the enforcement of rules and of cooperative behavior more complicated. Many informal institutions and their enforcement through social sanctions work only if majority of the society follows them. If not, these norms erode and they are continuously abandoned by the rest of the society due to pressures on conformity, social learning and other factors. The effect of enforcement is illustrated in Figure 2.2. Here, the presence of any enforcement mechanism is modeled as a chance of detection. It is assumed that if the predator is detected, his property is confiscated and distributed equally to every member of the population. Keeping the discussion as simple as it gets it is assumed, that existence of such probability of detection keeps the loss function and the function of producers' payoff untouched. Hence, only the expected payoff of predators decreases, that moves the productive equilibrium to the left, to higher income. The location of the second two equilibria after the enforcement mechanism is adopted and ready to use shifts either to

5 Acemoglu (1995) provides a proof, that the case of multiple equilibria corresponds better to the reality.

the right or they might diminish, as shown in Figure 2.2. This effect depends on the specification of the loss function.

Figure 2.2: Effect of Adopted Enforcement Mechanism



Final considerations are connected with the relevancy of the concept of predators and producers and their interactions for the theory of economic development. The model suggests that the countries with high production and good institutions should have low share of predators. The explicit measurement of the share of predatory behavior on the one side and of the cooperation on the other is, however, rather unrealistic. On the other hand there are many indicators that reflect the prevailing type of behavior in the society.

Such implicit approaches assume that in case of low proportion of predators the need for the monitoring costs and other costs of protection decreases. Furthermore societies with low share of predators can be often characterized with high trust among its members. P. Keefer and S. Knack (1997a, 1997b) used the data obtained from the World Values Surveys[6] and they estimated the level of social capital in each participating country based on indicators of trust. They found that these institutional variables explains a significant share of the variability in the data on economic growth that remains unanswered if only the savings rate and schooling variables are included in the model. Analogous findings were demonstrated by P. Johnson and J. Temple (1998): They summarized the Adelman-Morris index of socioeconomic development from the sixties (Adelman-Morris, 1968) that was based on indicators like share of middle class, social mobility, literacy, policy dualism and the like. Then they showed that this index, stressing importance of the institutional variables instead of the current economic performance or the level of investment gave much better predictions about the future success of developing countries than the competing indices based on economic indicators only[7].

3. A Computational Model of Producers and Predators

The implications of the analytical model from previous section (and from the similar ones) are straightforward. If the model leads to more than one stable equilibrium, it is possible to order these equilibria with respect to the overall social welfare in each of them. Then the equilibrium with the higher proportion of producers is socially optimal[8], because the income of individuals of both types is the highest.

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6 World Values Surveys are global sociological surveys where people are asked to fill questionnaires with questions on trust to another people, to other communities, to political representation or there are asked about their attitudes to violations of rules and laws such as bribes, cheating on taxes, avoiding fares on public transport etc.

7 Raiser et al. (2001) used similar approach to evaluate the success and potential perspectives of the countries in transition. Their findings – that better perspectives have countries with better institutions and larger social capital – are in accordance with findings of Johnson and Temple (1998).

The essential point of the model is that it doesn't contain any force, that could push a society from the equilibrium with a very low living standard into the high-production – high-income state. However, the historical experience reported elsewhere shows that the shift between the two equilibria requires high efforts and it is associated with almost prohibitive costs that make it often impossible. The cases of the Spanish or the Swedish Empires from the early modern times might serve as good examples. Both of these empires experienced rapid increase of power and wealth due to colonial expansions and wars. That is due to excellence in piracy and other forms of predatory behavior. After several decades the trend reversed and the inflow of wealth into the domestic countries started to decrease. None of these countries was able to make a shift to productive activities or trade that could substitute the piracy. Instead, a long period of decline and poverty followed.

Such abidance in inferior state seems to contradict the traditional rational choice approach. It would imply socially efficient outcome especially in a long-term, because if benefits of another actions become known, this opportunity will be utilized by agents in order to maximize their utility and welfare. Such presumption might hold in communities with homogeneous population, but once the heterogeneity in wealth or bargaining power is considered, the situation complicates. Heterogeneity of agents might cause that even in inferior equilibrium there is number of agents that are better off and who can feel endangered by any change. These agents, usually the most successful members of the community within given institutional set can form coalitions and create interest groups preventing any change. Recently, this could have been observed in transition countries in Central and Eastern Europe. In many of these countries, rent seeking and state capture slowed implementation of regulative rules at financial markets or reforms of state administration for example.

D. North describes this idea of elites with endangered status and wealth using an abstract concept of the institutional equilibrium: a state in which, given bargaining positions and given set of contracts, none of the agents finds it advantageous to devote his resources into restructuring them (North, 1990)[9]. Hence, societies with high share of rent-seekers within elites choose for higher enforcement of property rights less likely comparing to societies with a strong tradition of culture of cooperation. Consequently, the change of institutional path is more likely discontinuous and it often follows after an external shock (like war or revolution) that changes the perception of current institutional set.[10]

Concerning the possibility of attaining the socially efficient outcome it depends on two aspects that are often taken as given in both static and dynamic models. First, agents have to be able to recognize potential benefits of production to predation, despite predation is often more rewarded. Moreover, communities and societies need to develop mechanisms to enforce cooperative behavior from its members in order to prevent agents from a switch to predation. These mechanisms are usually backed by a central authority and implicitly followed by agents influenced by cultural norms and habits. Hence the macrodynamic behavior is a consequence of decentralized decisions of individual agents and so parallel to the top-down approach, the bottom-up dynamics should be considered, too.

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8 That is, it Pareto dominates the other equilibria as shown in Acemoglu (1995).

9 Later on D. Acemoglu introduced similar concept called political equilibrium. Suppose, that members of the community are able to affect the form of institutional set either directly by voting or indirectly through rent-seeking. According to the median-voter theorem the more frequent behavior is, the higher is the probability that this behavior prevails (Acemoglu, 1995). Both concepts imply that if those, who are allowed to decide, asses, that the current state is sustainable, there is no force that would cause change of the institutional set.

10 Concerning the institutional reforms in CEE countries, Grabbe (2001) describes how the E.U. accession process helped to overcome problems of rent-seeking. On the other hand number of problems prevails, like systematic policy and regulation of land-use or sustainable pension and health systems.

At the most elementary level, social dilemma of this kind can be formulated as a mixed-motive, two -person game with two choices: Either follow the rule "Cooperate", that means be honest, truthful and in this context devote your resources to productive activities. Alternatively behave according to the "Defect" rule, which encompasses all non-cooperative behavioral regularities, such as lying, cheating, stealing and so on. These two choices make a set of four possible outcomes with different payoffs. Usual structure of payoffs corresponds to the so called Prisoner's dilemma game (Table 3.1). It can be seen that in this game both agents prefer playing "Defect", at which they are always better off, disregarding the action of the concurrent agent – the Nash equilibrium of this game. Indeed, if these agents were able to negotiate before and to find an efficient way of enforcement of the cooperative behavior, the social welfare will be higher. The effect of culture of trust will be the same. However if they couldn't trust each other, conflict between the rational choice at the individual level and the socially optimal outcome arises.

Table 3.1: Prisoner's Dilemma

	Cooperate	Defect
Cooperate	R,R	S,T
Defect	T,S	P,P

Temptation, Reward, Punishment, Sucker
Assumed payoffs: T > R > P > S

Corresponding to previous model producers represent cooperative behavior. On the contrary predators correspond to rent-seekers, predators and any other forms of diverse behavior. The interactions with the payoff structure from the Table 3.1 symbolize actions like joint production motivated by increasing returns to scale or trading contracts and similar forms of economic activity that require interactions with another agents. And, if the game is played by two agents who choose "Cooperate", then both are better-off. On the other hand if one plays "Defect" he appropriates the whole product. Finally if both agents behave like predators, their payoffs are very low as both try to hedge against defect action of the other agent or no one invest enough energy to utilize maximum of the potential payoff.

If the game is played once the game theory gives precise solution as there is only one Nash equilibrium in this game. However in more complex settings – games with more players or with repeated interactions – more equilibria often arise and the dynamics (if any occurs at all) among them remains unclear. Also, the solutions of these games are based on forward-looking rationality that disregards from fundamental uncertainty and implies unrealistic cognitive demands[11]. Here, an alternative computational model to evolutionary the game theoretic approaches is used. It allows to model the interactions explicitly, incorporate the time dimension and explore the adjustment processes.

The model is constructed as follows. We assume an initial population of agents living in an environment provided with initial level of "natural" resources. These resources are source of energy for the agents. They are assumed to be partially renewable and the speed of renewing influences how easy life for the agents in their environment is. They might be linked either to grain or to any potential resources for redistribution, for example.

To survive, agents need to acquire energy continuously. It can be acquired either from the environment directly (utilizing that pieces of resources) or through interactions with other agents in order to produce or trade their goods. Each period, agents are allowed to move one step around. If

11 More detailed discussion can be found in Macy – Flache (2002), who present another alternative to the evolutionary game theory based on learning dynamics.

they don't find any resources or any other agent, one unit of their energy is lost. Hence, all effort of the agents is to get enough energy to survive and not to be starving. If the conditions are good they reproduce, whereas if their energy falls below zero, they die.

All agents are allowed to live infinitively. The only condition that they have to satisfy is to have their energy always strictly positive[12]. Three types of agents were generated in our model: the cooperating producers, the predators and finally number of random agents that mix the two basic strategies randomly, at 50% iterations they behave like producers and the remaining 50% as predators. All agents insist on their strategy for their whole lives. The population is growing by a growth rate that determines the number of new agents that invade the environment every 100 periods. These new agents choose their strategy randomly with the same probability of choosing any of the set of strategies.

Table 3.2: Structure of the Code
Definition of variables
Number of agents with each strategy, number of games, average score of each strategy Characteristics of agents *Score, strategy, color representing the strategy* *Whether the agent is engaged in interactions with another ones or not*
Setup
Initialization of environment *Setup patches with energy, set the volume of energy available at each patch* Initialization of agents *Create the appropriate number of agents with each strategy and distribute them randomly*
Runtime procedures
Let the agents to move randomly Select action of the agent *If they find a patch with a piece of energy, let them utilize it and increase the energy of that agent* *If they find a partner, let them interact (play the Prisoner's Dilemma game)* Update scores *Create the payoff matrix of the game* *Calculate updated scores and avegage scores per individual agent* If enforcement works... *Find those, who defected last round* *Punish some proportion of these agents* Population dynamics *If score of any agent falls below zero, let these agents die* *Each period, there is x% probability, that new agent invades and joins the community* *The new agents picks up his strategy randomly* Renew some resources *Each period, there is y% probability, that the energy of each patch is restored*

Interactions follow the simple prisoner's dilemma scheme. Success of each strategy is reflected by the number and scores of agents following that strategy. Those who are unsuccessful lose their energy continuously and die out, whereas the successful agents are able to acquire enough energy in environments with almost all resources consumed. This results into population dynamics in which the number of agents pursuing successful strategies steadily increases as both old and new agents

12 The assumption of the infinite horizons was not crucial, the basic advantage comparing to the overlapping generations style of model was that the generated trajectories were smoother for the infinite horizons.

survive. Therefore the population dynamics replaces learning algorithm at the individual level.

The simulations were run in the NetLogo environment (Wilenski, 1999). The logic of the simulation can be seen in Table 3.2 that shows the pseudo-code of the simulation[13].

The simulations differed in various aspects. First initial population might differ in the size and in the shares of agents with their strategies. Furthermore, the environment might be either rich or poor on natural resources. Finally agents might be able to detect those, who don't cooperate, but defect (the predators), and punish them. It was implemented as an exogenously given probability of detection here[14]. In case of detection, predator is punished by penalty of 50 units of energy. This size was chosen arbitrarily, usually it was high enough to cause death of punished agent.

4. Simulation Results

This section presents the results. The baseline setting of our simulation was as follows. At the beginning 30 agents were created, 10 were producers, 10 pirates and 10 followed random behavior ("Randoms") as described in the previous section. These numbers were chosen in order to have a sufficient number of agents to assure, that opportunities to interact arise and autarky does not dominate in the simulations. Then, the penalty imposed on the pirates that had been detected in the last round was set to 50. This value was usually sufficiently high to cause death of that particular agent in most of the settings. Those who survived this punishment belonged to the richest pirates before. Remaining parameters are summarized in Table 4.1.

Table 4.1: Parameters of Simulations

Producers	10
Predators	10
Randoms	10
Penalty	50
Population growth	3% (3 new agents in 100 rounds)
Energy form grain	1; 2.5; 5; 10
Detection probability (d*x*)	0; 1; 2; 3; 4; 5; 10; 15; 20; 25

The payoff matrix of the interactions (Table 4.2) corresponds to the prisoner's dilemma game. The values of energy from environment and the payoffs of interactions imply that for the energy at 10 autarky is worth to three cooperative and two defecting interactions. That is, the incentives for economic interactions are small and agents are able to get high income without any "risky" economic activity.

We ran 30 simulations for each of the settings to assure that the results are asymptotically consistent. Also, we did a number of sensitivity checks to find out whether the chosen setting

13 The code was compiled from the NetLogo PD N-Person Iterated Model, Wilenski (2002), the code as well as complete NetLogo file can be sent via email upon request.

14 The nature of enforcement was chosen to be exogenous because we believe that it is a good approximation to the situation at which some independent authority enforces the rules of the game and contracts, no matter whether it is the state or another organization. It doesn't imply that enforcement cannot be informal or that informal enforcement namely at the level of informal institutions doesn't work. However, such enforcement requires society that is sometimes able to punish its most successful members, too, in order to prevent erosion of their norms and institutions. This aspect might play an important role in modern societies with frequent economic changes at which plenty of new opportunities arise: informal mechanisms such as ostracism are often slow and work if the number of violations is low. Broad discussion about the nature of the enforcement and forms of enforcement of different institutional types can be found in Kiwit-Voigt (1995) or in North (2005) more recently.

affected the results or not. We have found that the initial setting of the proportion of strategies didn't affect the outcomes with the exception of energy-of-environment set over the value of 8. Starting at this point, the energy was so high that all agents accumulated the wealth very quickly and pursuing the interactions didn't affect the overall wealth.

Most of the simulations lead to trajectories of overall and average scores (energies) were growing over time. Although these nonstationary results might implicate non-ergodic world, where just few steps might shape the development, it was not the case here. After several hundreds of rounds the outcomes depend on the probability of detection and energy from environment. Only in case of energy from environment set to 1 the agents die often due to lack of energy and no growth emerges.

Table 4.2: Payoff Matrix

	Producer/ Cooperation	Pirate/ Defection
Producer	3,3	0,5
Pirate	5,0	1,1

The main issue of these simulations was to explore the conditions under which growth of welfare emerges. In accordance to our intuition, growth occurred in simulations where cooperative behavior prevailed. The only exceptions were connected with very convenient environments (with energy from environment exceeding 7.5, that corresponds to environment, where also predatory activities make lower benefits than passive gathering of crop or other forms of autarkical economic activity). Moreover, cooperation prevailed only if enforcement of cooperative behavior and when punishment of pirates was present. The relation between achieved welfare and detection probability is summarized in Figures 4.1 and 4.2 that show the average welfare after 10,000 iterations for different values of detection probability. The form of box-plot representation was chosen as it allows illustrating the distribution of resulting values for all 30 simulations with identical setting. Numerical summary corresponding to the box plots can be found in the Appendix.

Then, we applied the Wilcoxon rank sum test to test whether the differences in income between the two neighboring values of detection probability are statistically significant or not[15]. Resulting values of z-statistics are provided in table 4.3[16].

The main finding is that in general the effect of enforcement on welfare is positive and statistically significant for energy from environment similar to potential benefits of economic activity with other agents. Interestingly, the dynamics from low income states to high income states is ambiguous for low values of detection probability. First, introducing enforcement mechanism represented by the detection rate causes decrease in welfare as wealth of predators is lost and the share of producers was not affected by the change a lot. On the other hand more radical increase of detection rate has clear positive effect on wealth.

15 Because of observed distributions of income with fat tails, nonparametric test was preferred.

16 Negative value of z-statistics indicates increasing medians.

Table 4.4: Wilcoxon Rank-Sum Test Null hypothesis: the two medians are equal								
	d=0, d=1	d=1,d=2	d=2,d=3	d=3,d=5	d=5,d=10	d=10,d=15	d=15,d=20	d=20,d=25
env = 2.5	2,34 **	0,07	0,86	-1,61 *	-6,31 ***	-5,2 ***	-4,39 ***	-3,39 ***
env = 5	1,29 *	-6,05 ***	-4,27 ***	-6,46 ***	-6,58 ***	-1,98 **	-1,58 *	-0,72

Table shows z-statistics; * = significant at 10%, ** = significant at 5%, * = significant at 1%; env: energy from environment.

Figure 4.1: Average Welfare and Detection Rates

(Energy from environment = 2.5, 10,000 iterations)

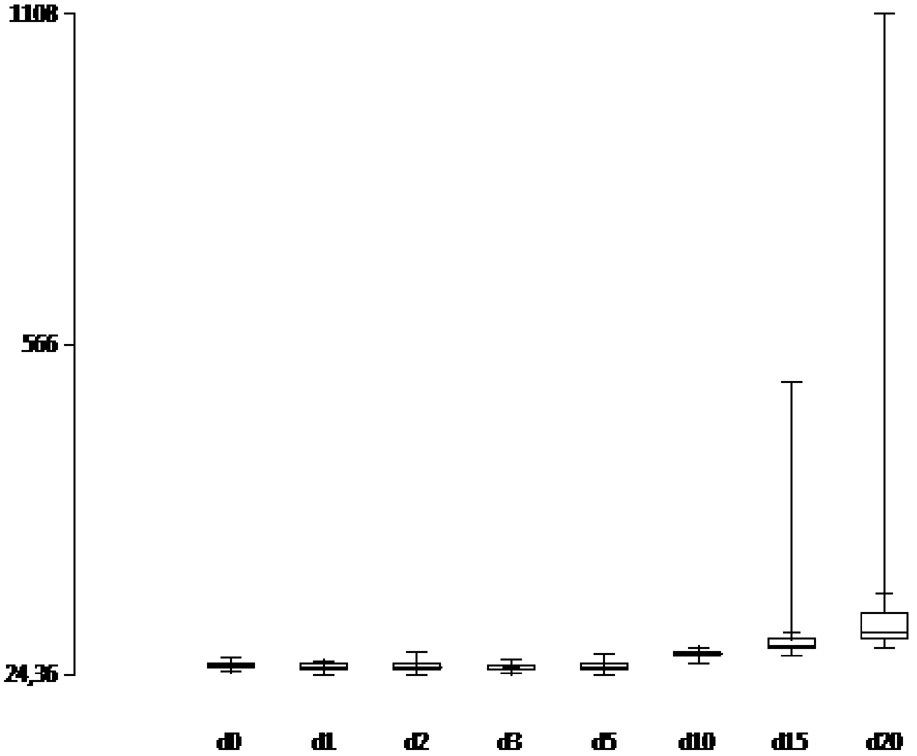
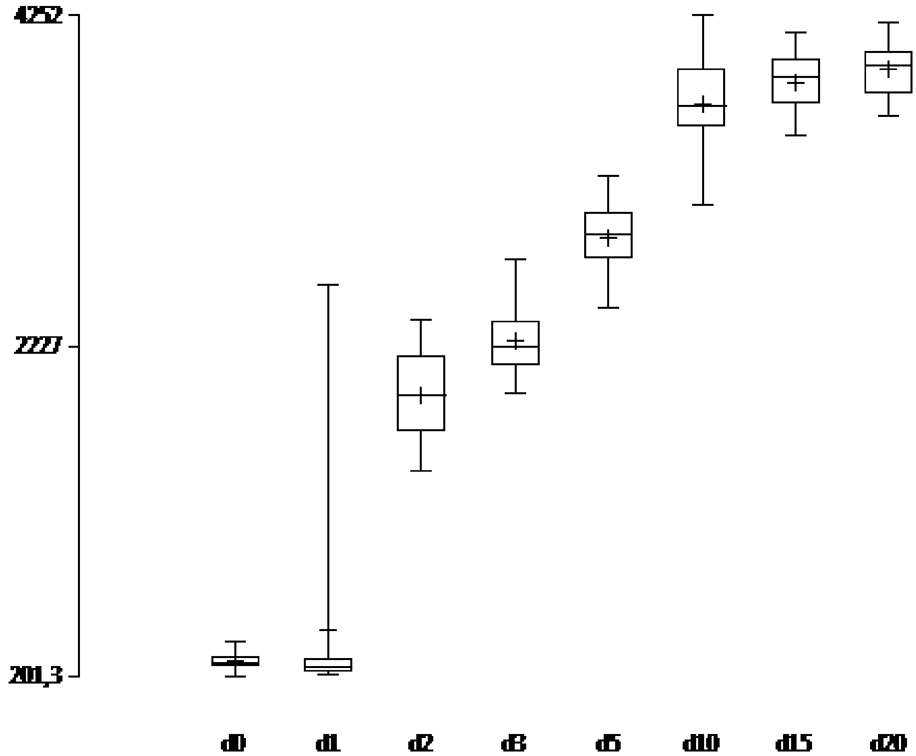


Figure 4.2: Average Welfare and Detection Rates

(Energy from environment = 5, 10,000 iterations)



As a matter of fact these simulations generate J-curve that changes into S-curve with increasing detection probability. The shape of the relation between the average wealth and detection rate implies dilemma of punishing the most successful members of the society and thus at the very beginning the newly established enforcement mechanism has negative effect on welfare. This can make a shift from the policy of "closed eyes" complicated regardless of the uncertainty about future effects of such shift and endangered status of elites, which were mentioned before.

Relative importance of these two effects depends on the energy that can be acquired from the environment. The evidence for the decreasing effect is stronger in poor environments with energy from environment from 1 to 2.5 than in good ones. When the energy is set to one, the population remains very small and no growth of wealth emerges. Hence, punishing of some members of the community decreases the number of the rich ones.

At 2.5, the energy is high enough to allow for growth of population and of the wealth. However the average wealth is still rather small and the differences among old and new agents are not significant. If the detection rate was small the generated proportion of producers is highly volatile, because it is influenced by new agents with predatory behavior (see Figure 4.3 for details). This volatility causes differences in timing of growth and thus observed average scores after 10,000 iterations exhibit fat tails that occur in Figure 4.1. The volatility decreases when the detection probability exceeds 25%. It illustrates that communities living in unpropitious environment have to be more strict in enforcing cooperative behavior in order to succeed and prosper.

For more favorable conditions (values of energy from environment were between 3 and 7.5) the observed trajectories followed the pattern presented in Figure 4.4. It can be seen that even at low levels of detection probability (2% for energy at 5) cooperation starts to dominate piracy, however the rent-seeking behavior is not eliminated. The last panel with detection probability at 10% shows that piracy dies out: after about 1000 iterations the proportion of cooperative behavior exceeds 90% and since then, the population of pirates consists almost from new agents only.

Figure 4.3: Proportion of Cooperative Behavior A

(Energy from environment = 2.5; d*x* = *x*% detection probability)

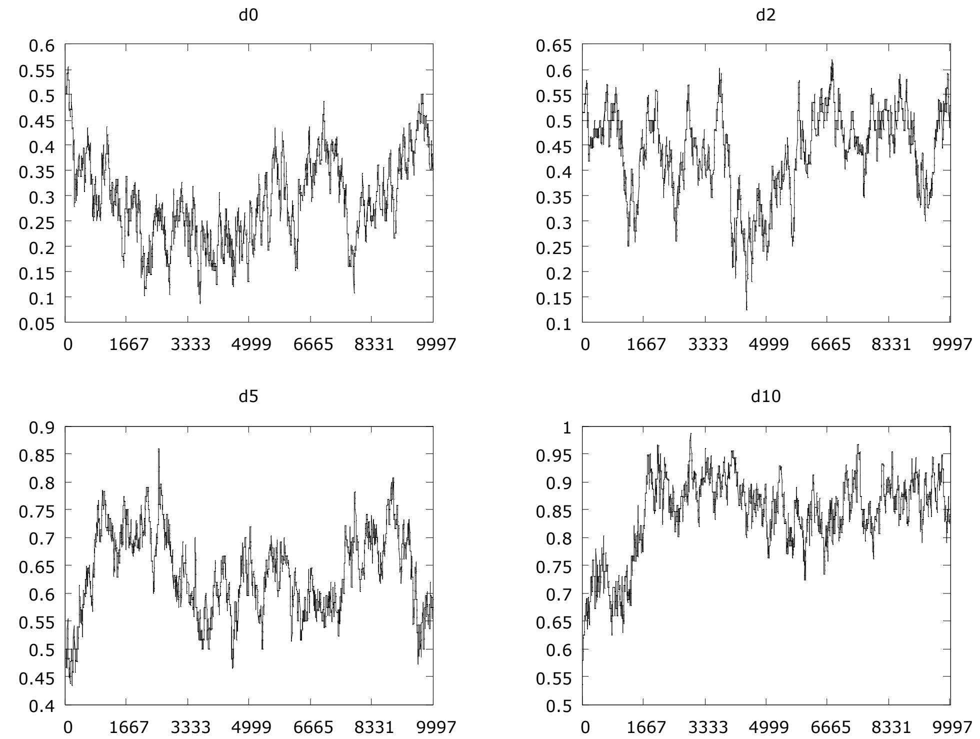
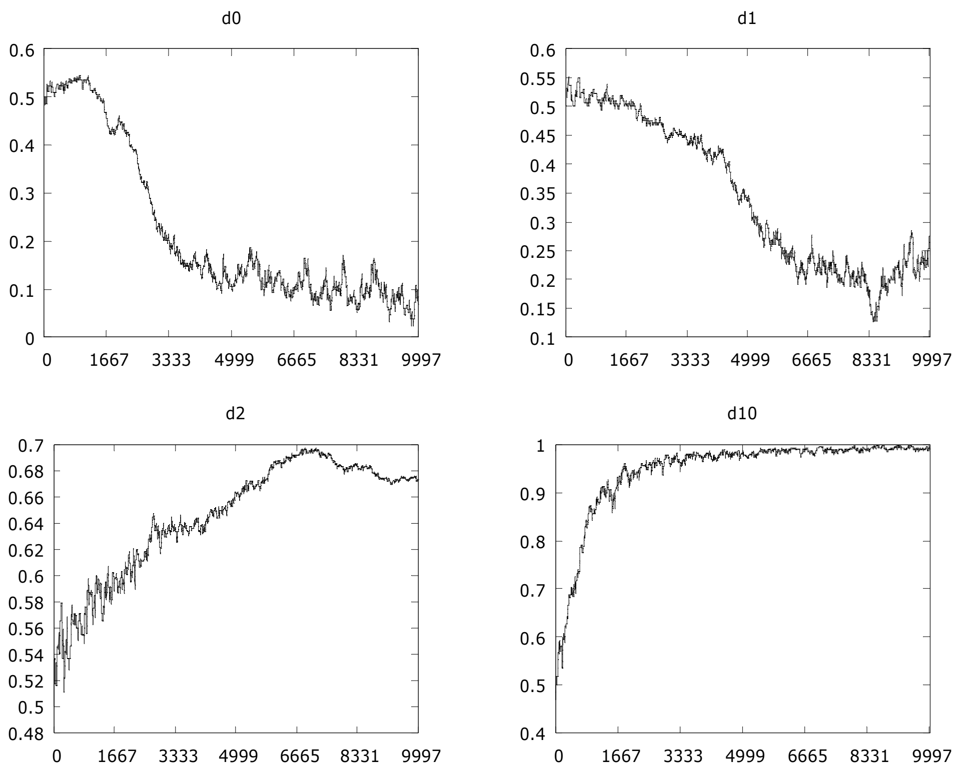


Figure 4.4: Proportion of Cooperative Behavior B

(Energy from environment = 5; d*x* = *x*% detection probability)



Figures 4.5-4.10 present more details about the evolution of simulated communities. For the same simulation settings the differences in the patterns of development were minor, except the few cases that caused fat tails in the simulations. More or less these sets of plots correspond to the median simulations. Figures 4.5 – 4.7 exemplify three different values of detection probability for energy from environment set to 5. Figures 4.8-4.10 illustrate the evolution for energy at 2.5. Each figure presents the evolution of populations of all three types of agents, the total score of the simulated society, the average score for each agent and finally the share of cooperative behavior.

If the ability to detect and punish predatory behavior is absent at all – as shown in Figure 4.5 – the society gets relatively rich quickly. Also numbers of agents pursuing all types of strategies are increasing from the beginning. However production is not rewarded enough to assure continuing sequence of mutual interactions between producers and shortly the population of producers falls to zero. After the population of randoms decreases, too: their strategy is advantageous if some producers are present. if they were absent, then the strategy "defect" is always better except the interactions of two randoms if both choose cooperate. Also, the situation for predators worsens, because since their strategy dominates the others, most of the interactions ends with the socially suboptimal outcome and no agent increases the overall product that can be utilized. In consequence both total and average score turn to decrease and long-lasting stagnation.

On the other hand existence of nonzero detection probability (Figures 4.6 and 4.7) leads to steady growth of population and the detection probability determines whether only cooperative producers survive or whether also the populations of predators and randoms persist or even grow. In both cases the total and average score are increasing as well.

Following Figures 4.8-4.10 document the simulation results in case of unfavorable environment. If the energy from environment were at 2.5 or lower none of the strategies are successful enough to be able to form sustainable population for values of detection probability below 10. All agents die out quickly and hence the relative importance of the new agents is larger than in previous cases. At the detection probability at 10 the situation reverses and the benefits of cooperative activities become more evident, although their effect is limited on the number of agents and the structure of the population. The income is slightly higher than for lower value only, but it is statistically significant even at 1% level, as documented in Table 4.4. Then the increasing detection probability decreases the prospect of pirates even more and the income increases. Also some small number of simulations lead to growth trajectories similar to Figures 4.6 and 4.7.

To complete the discussion about the role of enforcement in different environments we shed light on the effect of energy over 7.5. Starting this value, the environment is so favorable that utilizing its resources is more beneficial than any other economic activity. Consequently all agents get relatively rich (comparing to previous cases) quickly no matter what strategy they pursue. If the enforcement mechanisms were absent or its rates were very low, predation is rewarded more than production but the population of producers and randoms, who sometimes cooperate on production, also increases. After hundreds of iterations a number of cooperative agents exceeds 100. This number is sufficient to generate enough interactions among producers to give them resources to survive. Hence sustainable growth emerges also in simulations with the detection rate at 0.

To assess the role of cooperation we run a number of simulations with predatory and random strategies only. The findings showed that no matter what the energy from environment was, growth was no sustainable without producers. Also in very favorable environments the population reached the limits similar to the Malthusian trap: there were not enough resources to keep all agents alive and their mutual interactions were not sufficient for growth. As far as relevancy of this case we believe that it is rather implausible to expect such relative benefits from autarky represented as utilization of resources from the environment than from more complicated economic activities that require coordination of activities of more individuals. But then in case of successful coordination all can benefit from returns to scale.

Figure 4.5: Dynamics of the Simulated Economy 1

(Energy from environment = 5; 0% detection probability)

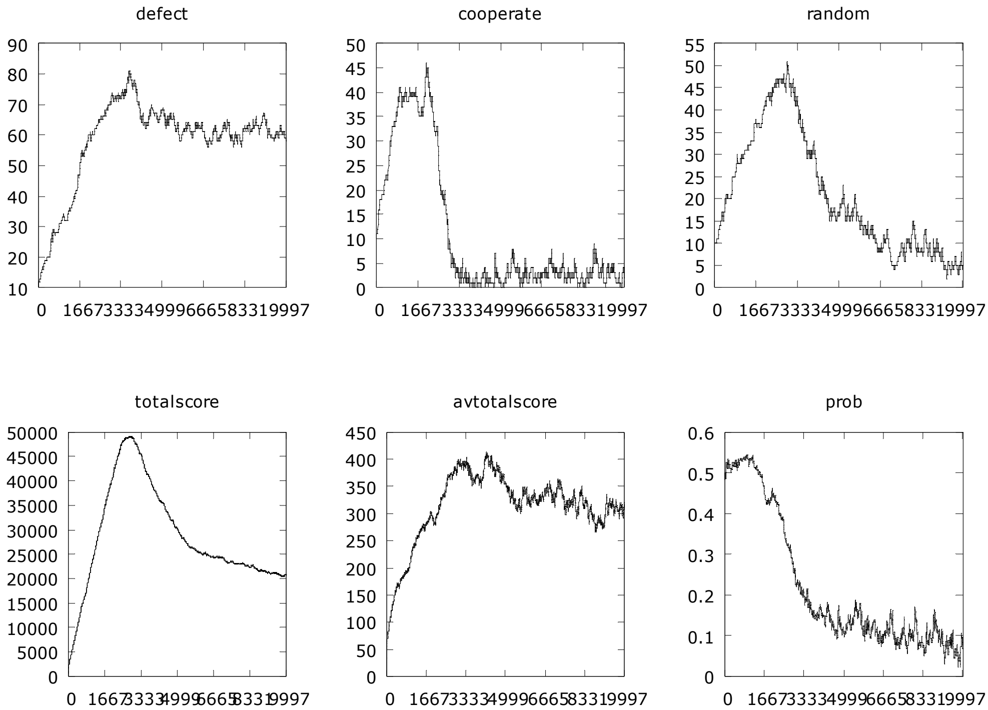


Figure 4.6: Dynamics of the Simulated Economy 2

(Energy from environment = 5; 2% detection probability)

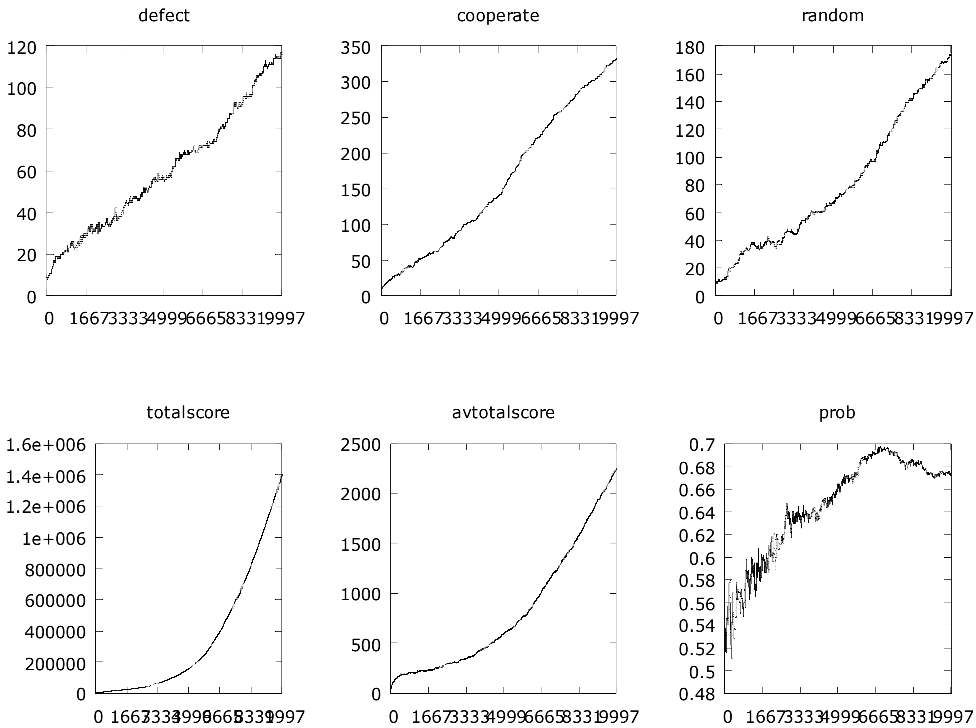


Figure 4.7: Dynamics of the Simulated Economy 3

(Energy from environment = 5; 10% detection probability)

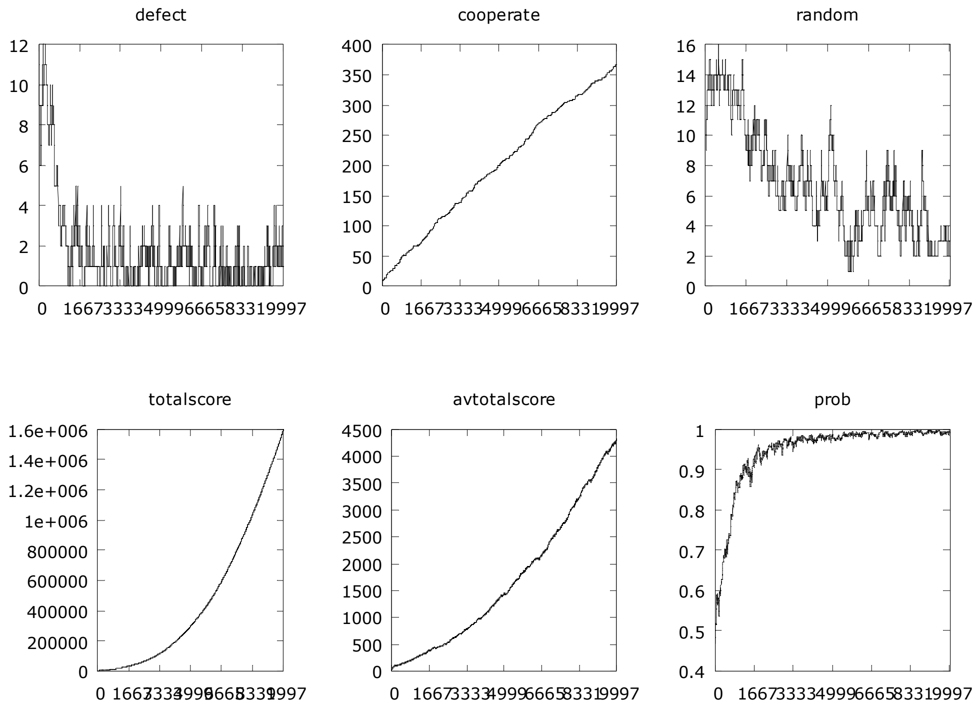


Figure 4.8: Dynamics of the Simulated Economy 4

(Energy from environment = 2.5; 0% detection probability)

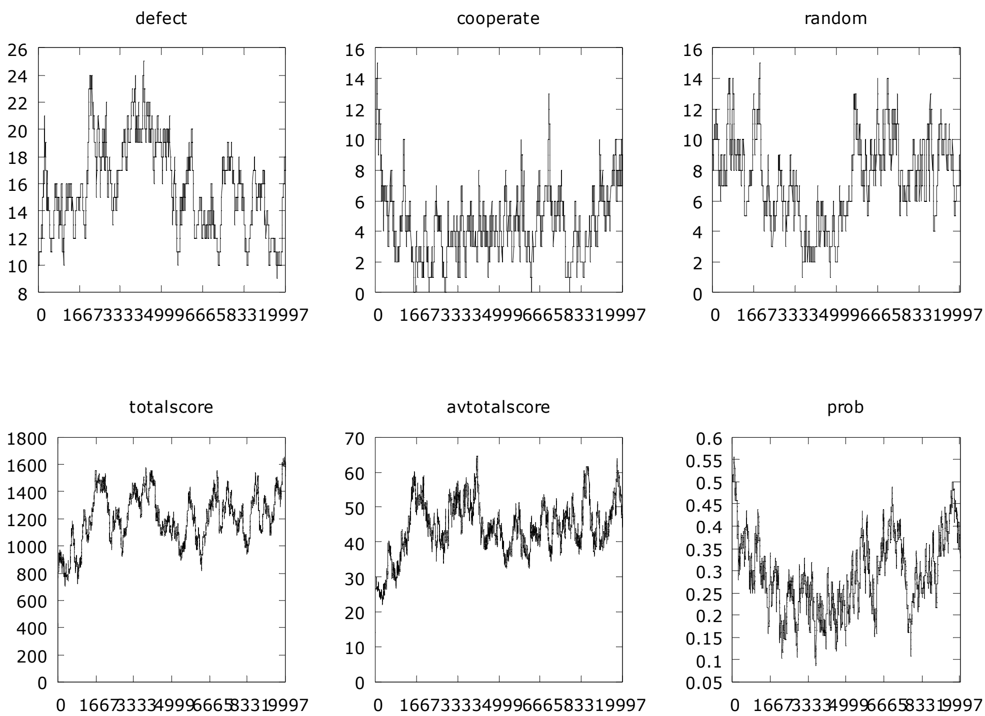


Figure 4.9: Dynamics of the Simulated Economy 5

(Energy from environment = 2.5; 5% detection probability)

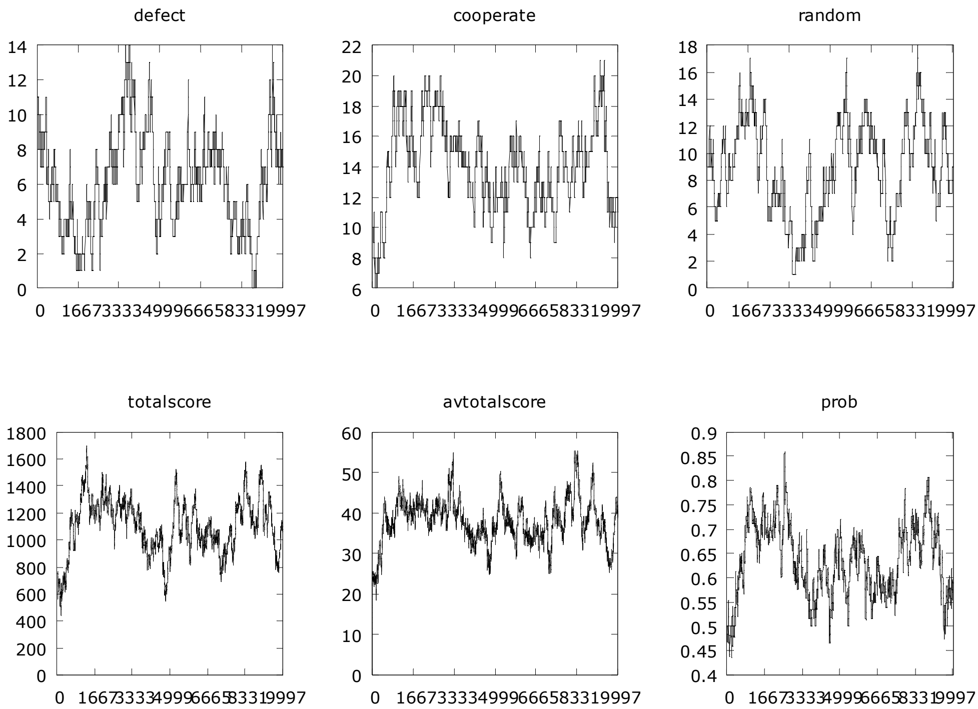
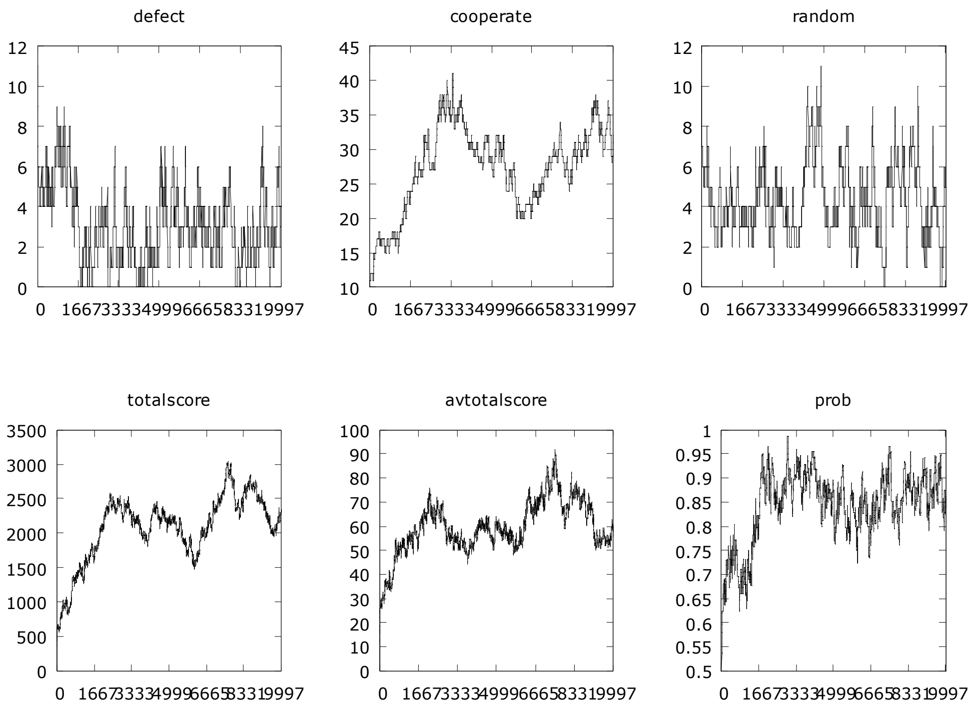


Figure 4.10: Dynamics of the Simulated Economy 6

(Energy from environment = 2.5; 10% detection probability)



The final simulations explore the process of institutional change. Suppose that the simulation starts without any enforcement mechanism as assumed in the situation depicted in Figure 4.5. After 1000 periods a new enforcement mechanism is introduced and since that time the external conditions are set in order to favor production against piracy. At this time, the average score of all strategies is still growing and the average predators' payoff is about twice so high as the payoff of producers and of random agents. However, its growth rates are gradually decreasing, continuation of the same institutional set will lead to stagnation and productive activities will be eliminated. Here we abstract from the cognitive aspects like "How do they know that if they don't adopt any mechanism protecting producers, they will face long-lasting stagnation?"[17]. For simplicity it is assumed that similarly to the external nature of enforcement mechanism its implementation is given. Then the resulting dynamics is explored.

In accordance to the existing literature on institutional change two types of institutional change are considered. The first case presented in Figures 4.11 and 4.12 describes the radical discontinuous change. In this case since time 1000 the detection probability jumps from 0 to 10%. In response to this change non-cooperative predators face to important losses, first they loose their wealth and after their number decreases, too. Following this change the share of agents playing "Cooperate" increases from 55% to 80% within 500 iterations after the change. Nevertheless the effects on output are devastating. In the particular simulation corresponding to the Figures 4.11 and 4.12 the average score falls from 231 to 179 in 100 periods namely because the fall of average score of agents playing "Defect" and "Random". The growth of income of producers that could compensate this fall starts after the next 200 periods, around 300 iterations after the change. Since then both average payoff of producers and their number gradually increase. Slowly the total average score recovers. After 800 iterations after the institutional change the average score exceeds its previous level (at the time of the change).

Clearly, the shift to the economy based on production is quite costly. The costs are distributed unequally and most of them are levied on predators, the former elites. On might object, that this fall is not very realistic because it is a consequence of rather simplistic assumptions of the model, namely inability of learning of individuals. On the other hand learning and acquiring new knowledge takes some time, and namely at the level of organization it is often difficult and costly process connected with various risks. Hence it is hard to expect quick adjustment to the new conditions. Moreover the population dynamics together with high number of iterations compensate the lack of learning at the individual level.

The second institutional change was continuous. At time 1000 a new rule was adopted and the detection probability increased to 1%. After 100 iterations the situation repeated and the detection probability increased again by 1% and so forth up to the point when it reached 10%. The situation is shown in Figures 4.13 and 4.14. During hundreds of iterations nothing happens and the simulated economy seems to follow its original path. Also the share of cooperation doesn't change significantly. Shortly after the detection rate increases to 3% the average output falls, again most of this fall is related to agents who follow predatory and random strategies. Then a period of stagnation follows and the average output is gradually decreasing between the periods 1500 and 2100. Later on the trend reverses and the economy turns to the growing trajectory. At this time, it is 200 periods after the detection rate achieved the final rate of 10%, but at the same time when the probability of cooperation exceeds 80%.

To sum up the simulations of institutional change lead to similar results as previous simulations with fixed parameters in both qualitative and quantitative respect. Moreover it confirmed our finding about temporarily negative effect of enforcement, too.

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17 This topic is extensively discussed in Matzavinos (2001).

Figure 4.11: Discontinuous institutional change

(Probability of detection increased to 10 at time = 1000)

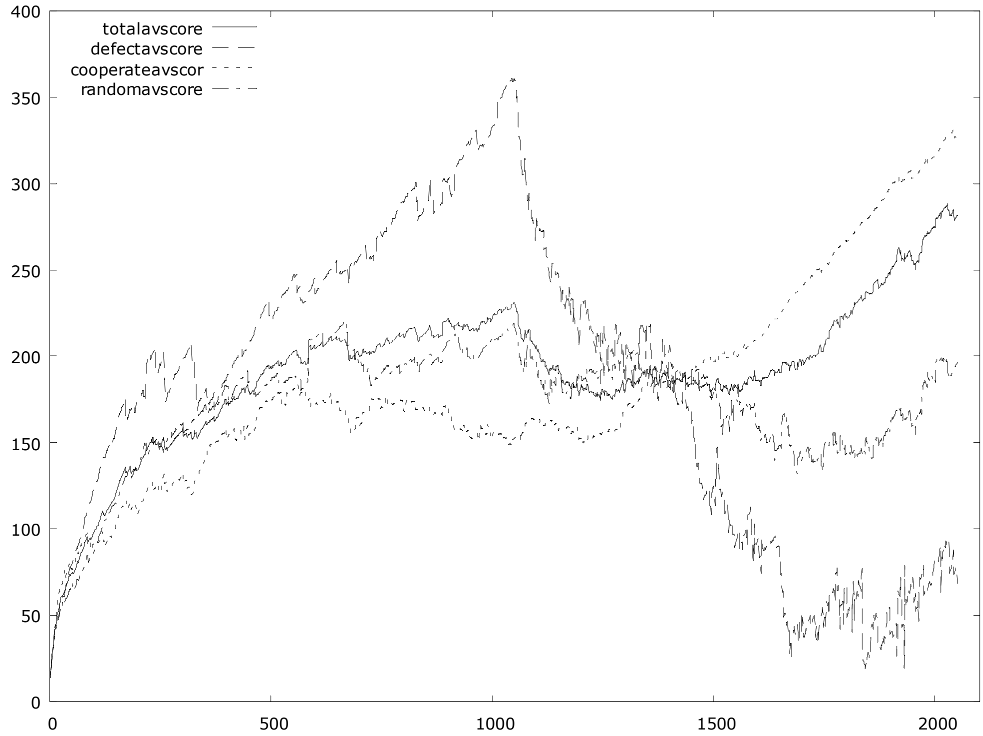


Figure 4.12: Discontinuous institutional change

Evolution of the share of cooperative behavior

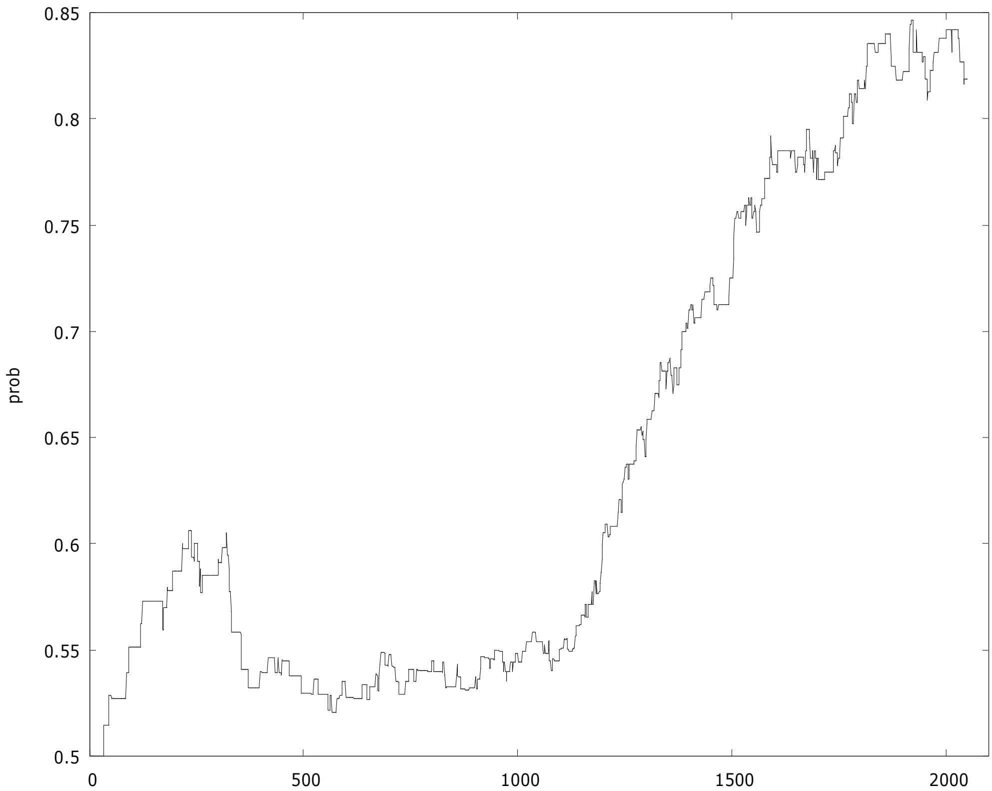


Figure 4.13: Continuous institutional change

(Probability of detection increases by 1% between 1000 and 1900 up to 10%)

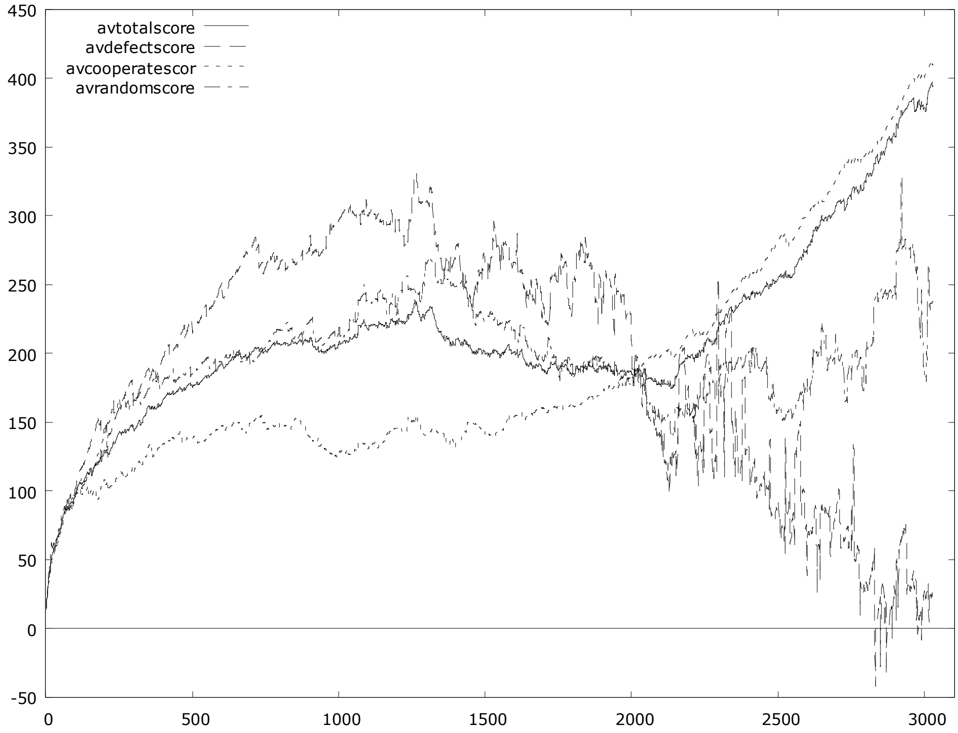
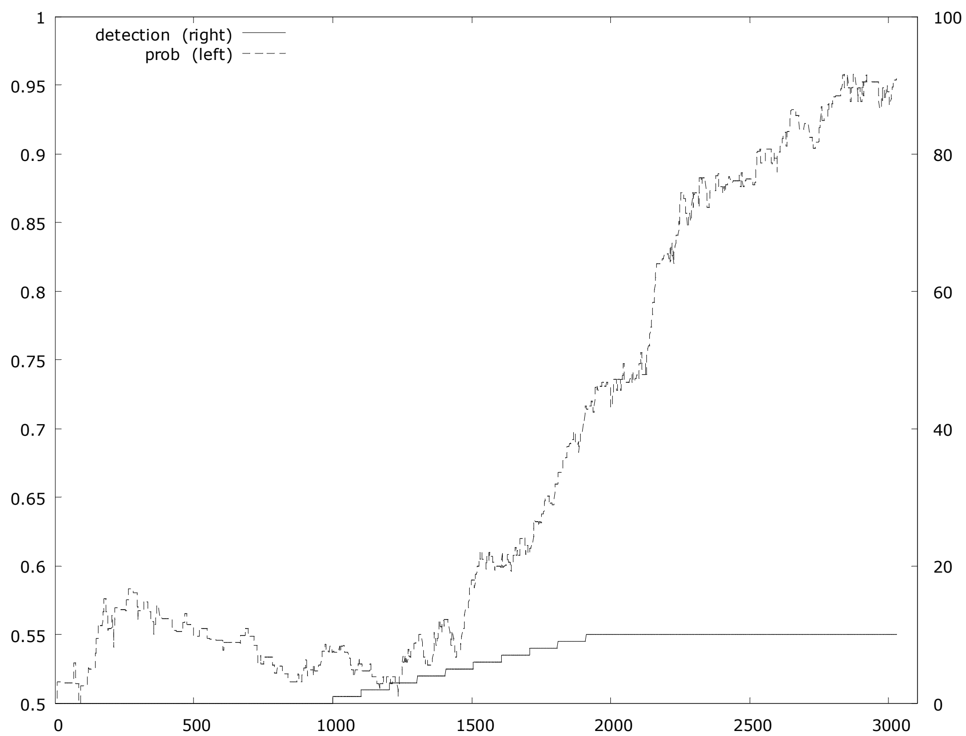


Figure 4.14: Discontinuous institutional change

Evolution of the share of cooperative behavior



5. Conclusion

It is well known that institutions may affect economic performance. The institutions favoring productive activities, shortly cooperation, promote sustainable economic growth based on increasing productivity whereas the unproductive institutions giving high rewards to rent-seeking or other predatory activities lead to stagnation. Historical experience of many countries like Spain, Italy, Sweden or transition countries most recently tends to support this view.

Still, the problem of persistence of inferior institutions remains open. Recent research stressed the importance of cognitive aspects of institutional change along with the traditional approach based on transaction costs related to political process. Thus, if the institutional set rewards predation more than production then knowledge associated with predation spread within the society and production becomes less attractive.

This doesn't imply that no prosperity can occur in societies where predation is dominant form of economic activity. However, such prosperity has some limits given by the potential property that can be redistributed and at this point persisting institutional setting doesn't create opportunities for growth. Despite this incentive, most probably the institutional change won't happen. Elites might feel endangered by such change, this will change overall incentive structure and contemporaneous effects on average agent are due to specific knowledge unclear. In fact the society is attracted to inferior but stable equilibrium and the transition to high-production – high-income equilibrium is non trivial process with uncertain outcomes.

This study addresses these aspects of production and predation, economic growth and institutional change explicitly within a framework of agent-based economy. The main finding from the simulations is that no matter the external conditions (opportunities for redistribution) are, productive activities based on cooperation among agents are the key source of growth. In some specific cases production need not to dominate predation, but without producers the income of the other agents stagnates. On the other hand the worse the environment was the need for cooperation for sustainable economic growth increased. However the payoffs of the interactions were supposed to follow the prisoner's dilemma game, hence some enforcement mechanism that punishes predation was necessary to make the production attractive and persisting over time.

The simulations also show that effects of adoption of such enforcement mechanism are mixed. For low levels of enforcement rates the effect on income was even negative: the most successful agents were the predators and those were punished. But at the same time the number of cooperative opportunities expressed as the number of producers was still very low to generate income so high to compensate the loss of predators. These results occurred in simulations with ability to enforce cooperation constant or time varying over time (simulations of institutional change caused by external change of enforcement ability). Thus the fears of change that might have been perceived by most successful agents, the elites, came true. The recovery came after a community of producers emerged; the delay was influenced mostly by the speed of inflow of the new agents. Nevertheless the effect of the change on income of producers was positive just from the very beginnings.

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Appendix

Numerical summary of Figures 1 and 2							
Energy from environment = 2.5							
	mean	min	Q1	median	Q3	max	n
d0	39,9	29,6	34,8	40,9	43,9	52,0	(n=30)
d1	36,1	24,4	31,6	36,0	41,1	45,1	(n=30)
d2	36,9	24,5	31,7	34,8	42,6	60,8	(n=30)
d3	35,0	25,4	30,6	33,1	38,9	49,3	(n=30)
d5	37,6	24,6	32,8	35,6	42,4	57,2	(n=30)
d10	57,8	44,0	54,0	57,9	61,2	69,3	(n=30)
d15	92,1	54,8	63,5	70,6	82,6	502,5	(n=30)
d20	157,3	68,8	83,1	93,8	126,6	1107,7	(n=30)
d25	375,5	77,6	101,1	222,0	577,4	1495,9	(n=30)
Energy from environment = 5							
	mean	min	Q1	median	Q3	max	n
d0	288,9	201,3	265,4	282,4	313,4	408,9	(n=30)
d1	479,2	205,4	233,0	261,6	307,5	2604,0	(n=30)
d2	1925,2	1455,6	1699,6	1918,5	2157,3	2382,4	(n=30)
d3	2255,1	1933,0	2104,9	2226,4	2373,0	2758,7	(n=30)
d5	2890,1	2461,1	2770,3	2910,8	3044,9	3273,4	(n=30)
d10	3712,5	3090,2	3560,5	3691,7	3917,3	4252,4	(n=30)
d15	3844,5	3519,8	3710,9	3878,9	3983,3	4144,3	(n=30)
d20	3918,9	3632,3	3771,8	3949,8	4032,1	4204,0	(n=30)