Akademie věd České republiky
Ústav teorie informace a automatizace

Academy of Sciences of the Czech Republic
Institute of Information Theory and Automation

RESEARCH REPORT

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COOPERATIVE BEHAVIOR AND ECONOMIC GROWTH

No. 2255 June 2009

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Cooperative Behavior and Economic Growth

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May 31, 2009

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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 activity. 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

* I would like to thank T. Cahlík, P. Švarc and M. Vošvrda for helpful comments. However, the usual disclaimer applies. Also the support of the Czech Science Foundation, grant no. 402/07/0890, the Institutional Support by the Department of Education MSMT 0021620841 and the Grant Agency of the Charles University in Prague (GAUK grant no. 139107) is gratefully acknowledged.

1. Introduction

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

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

The underlying hypothesis behind the institutionalist point of view is as follows. If 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 and Freeman, 2004).

Gradually, as the share of the population involved in productive activities decreases, a different set of abilities and knowledge linked with predatory activities and piracy emerges and spreads through society. Redistribution of wealth starts to dominate its creation and steady stagnation begins.[3]

In this paper, we investigate the relative importance of the ability to enforce cooperation 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 crops, for example – or engage 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 agents cooperate, they will both be better off. But if one or either of them defects, the product is either expropriated or deteriorates owing to the high monitoring and enforcement costs that have to be spent if the agents do not trust each other. The cooperative behavior represents actions associated with production of wealth hence cooperative agents are called producers whereas those who defect are predators. For simplicity, the learning algorithm is replaced by simple population dynamics leading to an increasing population of agents with successful strategies.

Even this simple setting allows us to explore how these simple economies evolve in different environments without the need for optimization or learning strategies based on knowledge of each agent's payoff. More specifically, the focus is on the conditions under which economic growth emerges. The conditions of the simulations differed in two aspects. Firstly, agents might be able to detect those who don't cooperate, but defect (the predators), and punish them. This was

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

2 Recently, the effects of trust and the culture of cooperation on economic growth have started to be emphasized; other economists are explicitly working with the concept of social capital following the tradition of modern sociology and work by Putnam (1995, 2000) and Coleman (1988).

3 Empirical studies supporting the view that institutions affect economic performance are extensively reviewed in Aron (2000).

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 in resources, the incentives for other economic activity are much lower, except for actions directly connected with exploiting them.

Our results show that cooperative behavior does not prevail in any community lacking 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 cooperation 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 such good resources that the size of the producer population quickly increases is economic growth 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 a mechanism causes elimination of the most successful agents without contemporaneous positive effects on cooperation and productive economic activity. Hence, income is lower for low enforcement rates than for economies without any mechanism supporting cooperation. A similar effect occurs in the simulations of institutional change. In the case of a discontinuous change, a radical enforcement mechanism causes a sharp fall of wealth in the short term. Nevertheless, in the long term the 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 limitations, lack of specific knowledge), can make such change unfeasible. As far as the 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 organized as follows. Section 2 contains literature overview, the prototypical model of producers and predators is shown in the Appendix. Section 3 introduces the implementation within a framework of a multi agent system. The next section presents our results. Finally, concluding remarks close the paper in section 5.

2. Literature Overview

This paper is related to various strands of research. The idea that social infrastructure and the institutional setting of the economy affect economic performance has been widely discussed by many economists during the last two centuries. In recent decades, the discussion about the effects of institutions on economic performance has turned to the question of why countries or communities insist on inferior institutional settings causing lower income. North (1990) explained the problem of switching the institutional path to another one using a parallel with technological change. From 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. Murphy, Shleifer, and Vishny (1991, 1993) and Acemoglu (1992) emphasize that predatory activities such as rent-seeking simply reward talent through making effort more than entrepreneurship and production do. If this material attractiveness of piracy and rent-seeking is not limited by social institutions, talented individuals are more likely to choose to be predators 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 a culture of cooperation and trust where production prevails. On the other hand, predators are more rewarded in the second group, where piracy dominates different types of economic activities. The existence of multiple equilibria allows different outcomes of different societies to be discussed within the general equilibrium framework. For example, Acemoglu (1995) generated poverty traps using this approach. Similar results to previous studies were obtained in series of articles by Kim and Grossman (1995, 1998, 2002). More recently Grossman (2002) published an interesting extension with a central authority that enforces the rules. He showed that the existence of such an authority is beneficial to both predators and producers because it protects the property of both, and thus also the property of predators against other predators. Mehlum et al. (2003) showed that for poor countries from the predators club the only way of escaping to the high-income producers club is through a massive inflow of new entrepreneurs that might outweigh the effect of old predators.

Furthermore, Dabla-Norris and Freeman (2004) attempted to develop a model in which enforcement ability was endogenous, determined by the shares of predators and producers in society. They showed that in this case, identical initial conditions might lead to equilibria both with and without high production. Nuun (2005) used these ideas to formulate a sequential game that helped him to explain the current underdevelopment of Africa. According to his paper, 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, investment opportunities will be lost to the domestic population, and in the second stage underdevelopment occurs. Wilhite (2006) applied the methods of agent-based computational economics to study different forms of protection against predators. Most recently, 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 might also help to ensure enforcement of property rights.

Our final considerations are connected with the relevance of the concept of predators and producers and their interactions to the theory of economic development. The models developed in Acemoglu (1995) or in Mehlum et al. (2003) suggest that countries with high production and good institutions should have a low share of predators. Explicit measurement of the share of predatory behavior on the one side and of cooperation on the other is, however, rather unrealistic. On the other hand, there are many indicators that reflect the prevailing type of behavior in society.

Such implicit approaches assume that in the case of a low proportion of predators the need for monitoring costs and other costs of protection decreases. Furthermore, societies with a low share of predators are often characterized by high trust among their members. Keefer and Knack (1997a, 1997b) used data obtained from the World Values Surveys[4] to estimate the level of social capital in each participating country based on indicators of trust. They found that these institutional variables explain 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 Johnson and Temple (1998). They summarized the Adelman-Morris index of socioeconomic development from the 1960s (Adelman-Morris, 1968), which was based on indicators such as middle class, social mobility, literacy, and policy dualism. Then they showed that this index, stressing the importance of institutional variables instead of 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.[5]

3. A Computational Model of Producers and Predators

The implications of the analytical models referred in the previous section (Appendix A provides more detailed discussion about their main ideas and structure) are straightforward. If the

4 World Values Surveys are global sociological surveys where people are asked to fill out questionnaires containing questions on trust in other people, other communities, and the political representation and on attitudes to violations of rules and laws, such as bribes, cheating on taxes, avoiding fares in public transport, etc.

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

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[6], because the income of individuals of both types is the highest.

The essential point of these models is that they don't contain any force that could push a society from an equilibrium with a very low living standard to a high-production, high-income state. However, the historical experience reported elsewhere shows that the shift between the two equilibria is nontrivial and not always successful. It is usually result of a sequence of intended actions of the elites and it is often associated with almost prohibitive costs. The cases of the Spanish and Swedish empires in early modern times serve as good examples. Both of these empires experienced a rapid increase of power and wealth due to colonial expansions and wars, i.e., due to excellence in piracy and other forms of predatory behavior. After several decades, the trend reversed and the inflow of wealth into the home countries started to decrease. Neither of these countries was able to make a shift to productive activities or trade that could substitute for piracy. Instead, a long period of decline and poverty followed.

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

D. North describes this idea of elites with endangered status and wealth using the abstract concept of institutional equilibrium: a state in which, given bargaining positions and a given set of contracts, none of the agents finds it advantageous to devote his resources to restructuring them (North, 1990).[7] Hence, societies with a high share of rent-seekers within their elites are less likely to choose higher enforcement of property rights than societies with a strong tradition of a culture of cooperation. Consequently, the change of institutional path is more likely to be discontinuous and often comes after an external shock (such as a war or revolution) that changes the perception of the current institutional setup.[8]

The possibility of attaining a socially efficient outcome depends on two aspects that are often taken as given in both static and dynamic models. First, agents have to be able to recognize the potential benefits of production over predation, even though predation is often better rewarded. Moreover, communities and societies need to develop mechanisms to enforce cooperative behavior by their members in order to prevent agents from switching 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, in parallel to the top-down approach, the bottom-up dynamics should

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

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

8 Concerning the institutional reforms in CEE countries, Grabbe (2001) describes how the EU accession process helped to overcome problems of rent-seeking. On the other hand, a number of problems prevail, such as systematic land-use policy and regulation and sustainable pension and health systems.

be considered, too.

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

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 the previous model, cooperation represents productive behavior. On the contrary, predators correspond to rent-seekers, and any other forms of diverse behavior. The interactions with the payoff structure from Table 3.1 symbolize actions such as joint production motivated by increasing returns to scale or trading contracts and similar forms of economic activity that require interactions with other agents. And if the game is played by two agents who choose to “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 the defect action of the other agent or no one invests enough energy to utilize the maximum potential payoff.

If the game is played once, game theory gives a 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 occur at all) among them remain unclear. Also, the solutions of these games are based on forward-looking rationality that disregards fundamental uncertainty and implies unrealistic cognitive demands.[9] Here, an alternative computational model to the evolutionary game theoretic approaches is used. It allows us 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 an initial level of “natural” resources. These resources are a source of energy for the agents. They are assumed to be partially renewable and the speed of renewal influences how easy life is for the agents in their environment. They might be linked to grain or to any other potential resources for redistribution, for example.

To survive, agents need to acquire energy continuously. It can be acquired either from the environment directly (utilizing pieces of resources) or through interactions with other agents in

9 A more detailed discussion can be found in Macy and Flache (2002), who present another alternative to the evolutionary game theory based on learning dynamics.

order to produce or trade their goods. In each period, agents are allowed to move one step around. If they fail to find any resources or any other agent, one unit of their energy is lost. Hence, all the agents' effort is directed at getting enough energy to survive and not to starve. 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 they have to satisfy is that their energy must always be strictly positive.[10] Three types of agents were generated in our model: cooperating producers, predators and, finally, a number of random agents that mix the two basic strategies randomly (in 50% of the iterations they behave like producers and in the remaining 50% they behave like predators). All agents insist on their strategy for their whole lives. The population is growing at a 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 other 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 agentsmove randomly Select the 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 average scores per individual agent* If enforcement works... *Find those who defected last round* *Punish some proportion of these agents* Population dynamics *If the score of any agent falls below zero, let that agent die* *Each period, there is an x% probability that a new agent invades and joins the community* *The new agent picks his strategy randomly* Renew some resources *Each period, there is a y% probability, that the energy of each patch is restored*

The interactions follow the simple Prisoner's Dilemma scheme. The success of each strategy is reflected in the number and scores of agents following that strategy. Those who are unsuccessful lose their energy continuously and die out, whereas successful agents are able to acquire enough energy in environments with almost all resources consumed. This results in population dynamics in which the number of agents pursuing successful strategies steadily increases as both old and new agents survive. Therefore, the population dynamics replace the learning at the individual level.

10 The assumption of infinite horizons was not crucial; the basic advantage compared to the "overlapping generations style" was that the trajectories generated were smoother.

The simulations were run in the NetLogo environment (Wilensky, 1999). The logic of the simulation can be seen in Table 3.2, which shows the pseudo-code of the simulation.[11]

The simulations differed in various aspects. First, the initial population might differ in size and in the shares of agents with their strategies. Furthermore, the environment might be either rich or poor in natural resources. Finally, agents might be able to detect those who defect rather than cooperate (the predators), and punish them. This was implemented as an exogenously given probability of detection here.[12] In the case of detection, the predator is punished by a penalty of 50 units of energy. This size was chosen arbitrarily; usually it was high enough to cause the death of the punished agent.

4. Simulation Results

The baseline setting of our simulation was as follows. At the beginning, 30 agents were created; 10 were producers, 10 were 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 ensure that opportunities to interact arise and autarky does not dominate in the simulations. Then the penalty imposed on the pirates detected in the last round was set to 50. This value was usually sufficiently high to cause the death of the particular agent in most of the settings. Those who survived this punishment were among the richest pirates before. The 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 the environment and the payoffs of the interactions imply that for energy at 10, autarky is worth three cooperative and two defecting interactions. That is, the incentives for economic interactions are small and agents are able to earn a high income without any "risky" economic activity.

We ran 30 simulations for each of the settings to ensure that the results are asymptotically consistent. Also, we did a number of sensitivity checks to find out whether the chosen setting affected the results or not. We found that the initial setting of the proportion of strategies did not affect the outcomes, except when the energy of the environment was set higher than 8. Starting at

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

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

this point, the energy was so high that all the agents accumulated wealth very quickly and pursuing interactions did not affect overall wealth.

Table 4.2: Payoff Matrix		
	Producer/ Cooperation	Pirate/ Defection
Producer	3,3	0,5
Pirate	5,0	1,1

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

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

Then we applied the Wilcoxon rank sum test to test whether the differences in income between two neighboring detection probability values are statistically significant or not.[13] The resulting z-statistics are provided in Table 4.3.[14]

Table 4.3: 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.

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

13 Because of the observed income distributions with fat tails, a nonparametric test was preferred.

14 Negative z-statistics indicate increasing medians.

Figure 4.1: Average Welfare and Detection Rates
(Energy from environment = 2.5, 10,000 iterations)

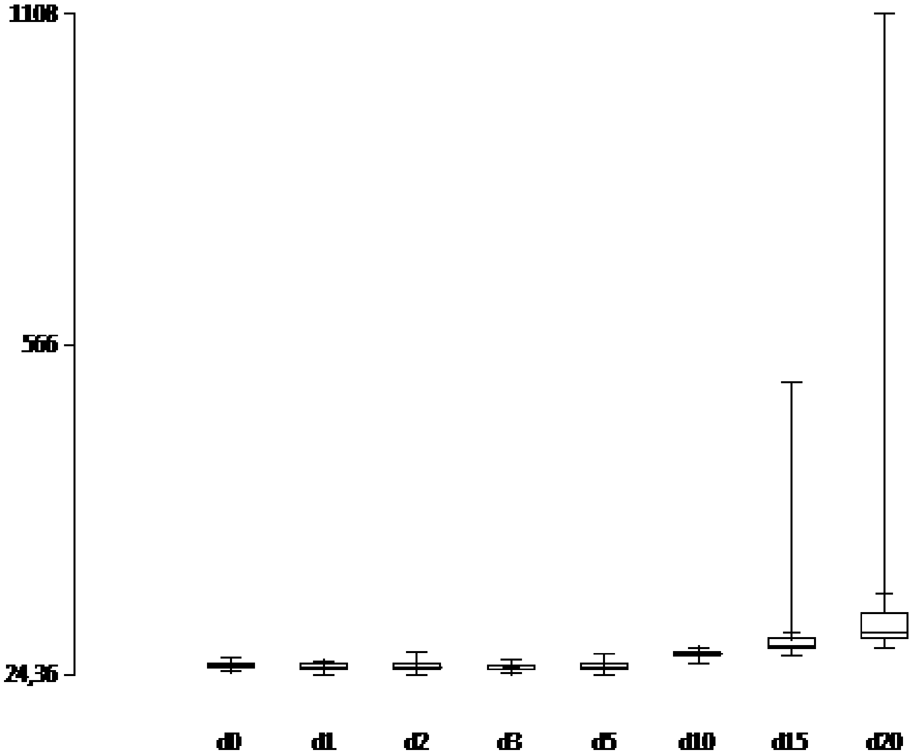
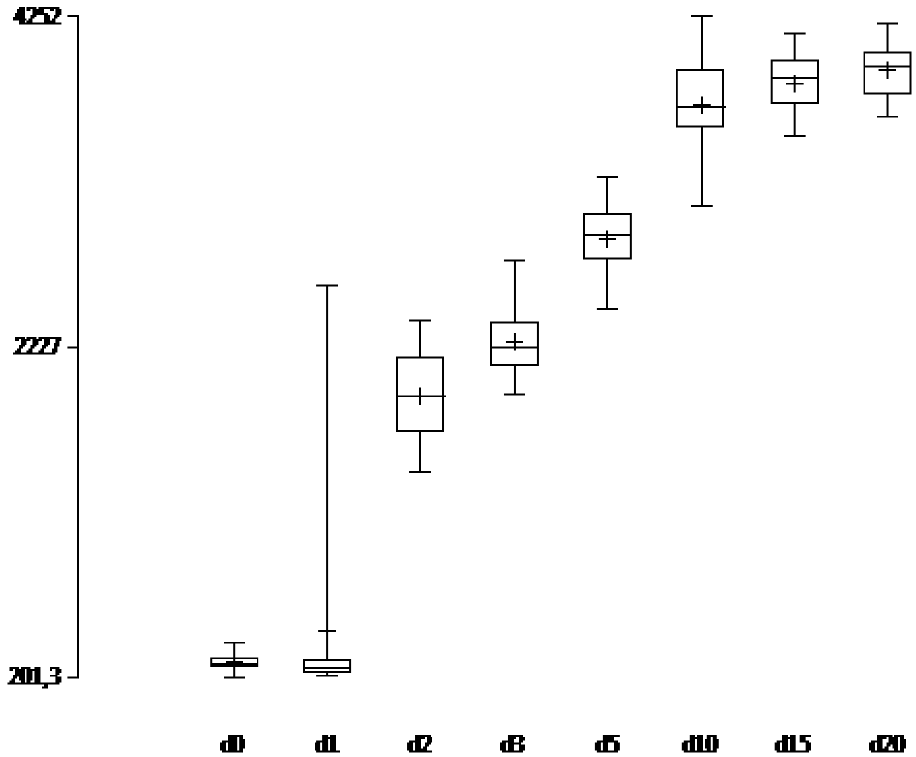


Figure 4.2: Average Welfare and Detection Rates
(Energy from environment = 5, 10,000 iterations)



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

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

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

For more favorable conditions (values of energy from the environment between 3 and 7.5), the observed trajectories followed the pattern presented in Figure 4.4. It can be seen that even at low detection probabilities (2% for energy at 5) cooperation starts to dominate piracy, although rent-seeking behavior is not eliminated. The last panel, with a detection probability of 10%, shows that piracy dies out: after about 1,000 iterations the proportion of cooperative behavior exceeds 90%, and from that point on the population of pirates consists almost exclusively of new agents.

Figure 4.3: Proportion of Cooperative Behavior A

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

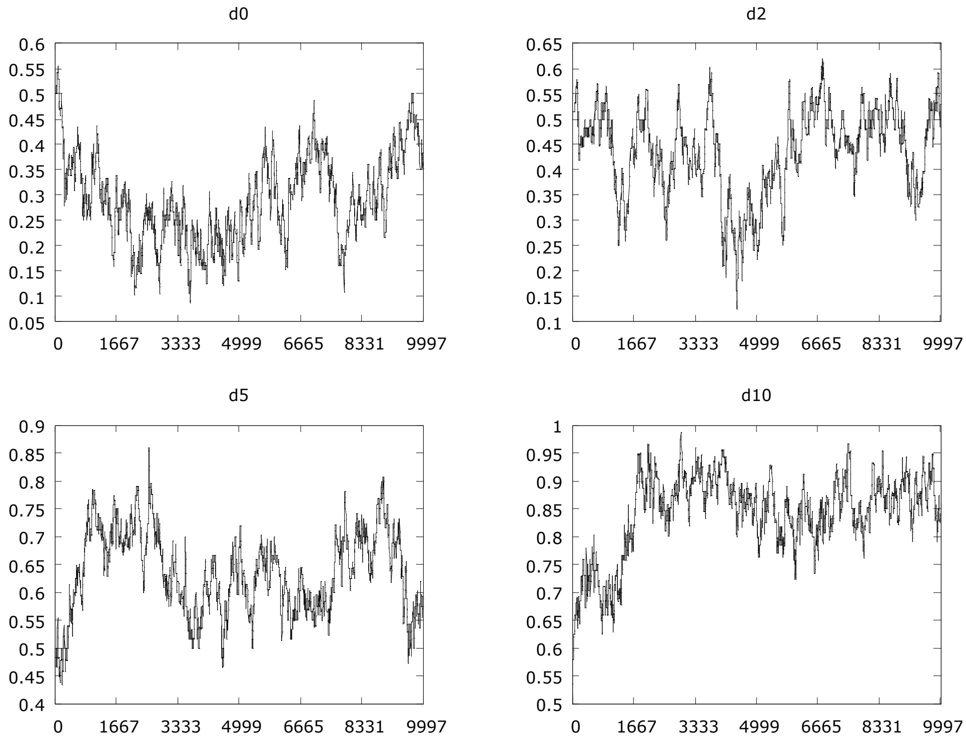
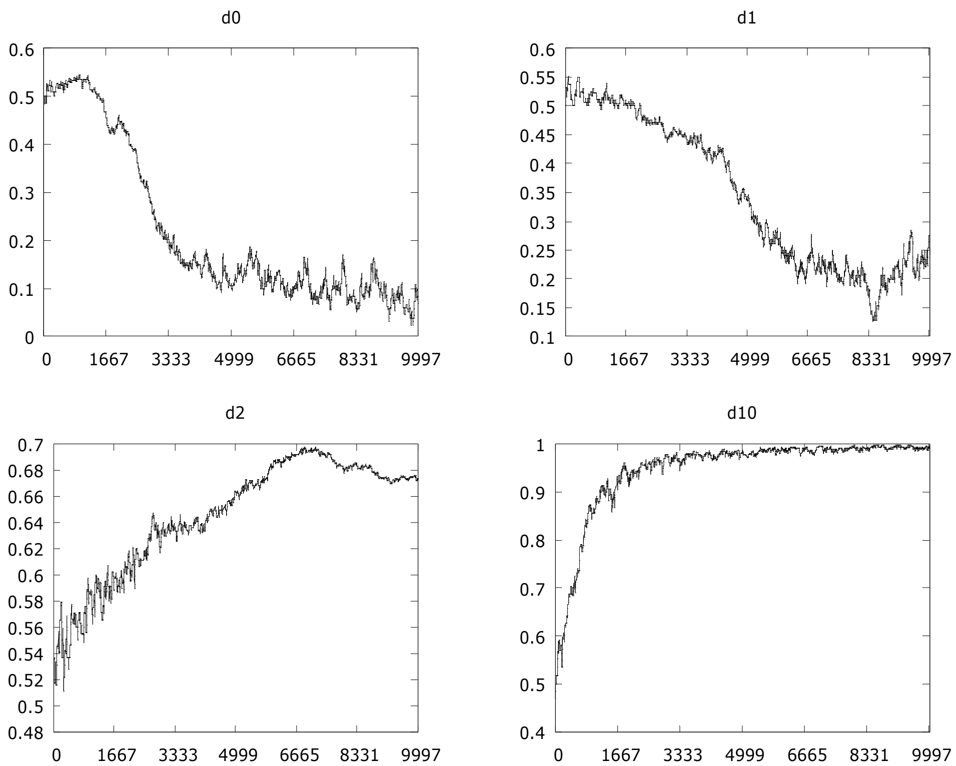


Figure 4.4: Proportion of Cooperative Behavior B

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



Figures 4.5–4.10 present more details about the evolution of the simulated communities. For the same simulation settings the differences in the patterns of development were minor, except for the few cases that caused fat tails in the simulations. These sets of plots more or less correspond to the median simulations. Figures 4.5–4.7 exemplify three different detection probabilities for energy from the environment set to 5. Figures 4.8–4.10 illustrate the evolution for energy at 2.5. Each figure presents the evolution of the 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 completely absent – as shown in Figure 4.5 – society gets relatively rich quickly. Also, the numbers of agents pursuing all types of strategies increase from the beginning. However, production is not rewarded enough to ensure a continuing sequence of interactions between producers and the population of producers soon falls to zero. Afterwards, the population of randoms decreases, too: their strategy is advantageous if some producers are present. if they are absent, then the "defect" strategy is always better, except for the interactions of two randoms if both choose to cooperate. Also, the situation for predators worsens, because since their strategy dominates the others, most of the interactions end with a socially suboptimal outcome and no agent increases the overall product that can be utilized. In consequence, both the total and average scores turn to decline and long-lasting stagnation.

On the other hand, the existence of a non-zero detection probability (Figures 4.6 and 4.7) leads to steady growth of the population, and the detection probability determines whether only cooperative producers survive or whether the populations of predators and randoms also persist or even grow. In both cases, the total and average scores increase as well.

Figures 4.8–4.10 document the simulation results in the case of an unfavorable environment. If the energy from the environment is at 2.5 or lower, none of the strategies are successful enough to be able to form a sustainable population for detection probabilities below 10. All agents die out quickly and hence the relative importance of new agents is larger than in the previous cases. At a detection probability of 10, the situation reverses and the benefits of cooperative activities become more evident, although their effect on the number of agents and the structure of the population is limited. Income is slightly higher than for lower values only, but it is statistically significant even at the 1% level, as documented in Table 4.5. Then the increasing detection probability decreases the prospects of pirates even more and 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 at 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 (compared to previous cases) quickly no matter what strategy they pursue. If the enforcement mechanisms are absent or the rates are 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, the 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 a detection rate of 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 the environment was, growth was not sustainable without producers. Also, in very favorable environments the population reached 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 for the relevance of this case, we believe it is rather implausible to expect such relative benefits from autarky, as represented by utilization of resources from the environment, compared to more complicated economic activities that require coordination of activities of more individuals. But then in the 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)

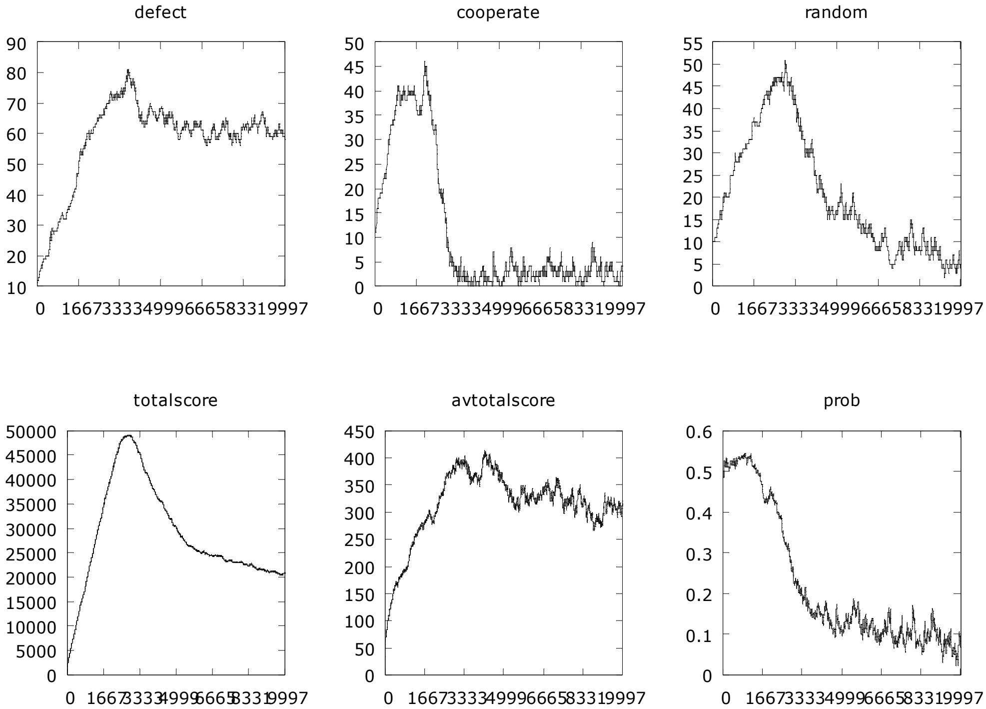


Figure 4.6: Dynamics of the Simulated Economy 2

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

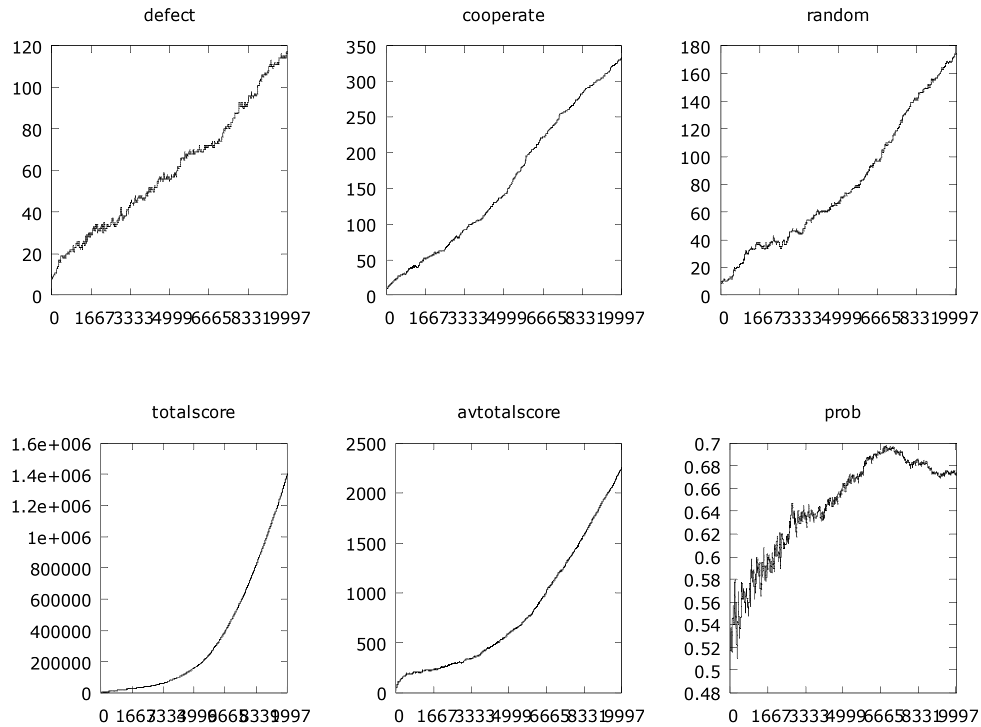


Figure 4.7: Dynamics of the Simulated Economy 3

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

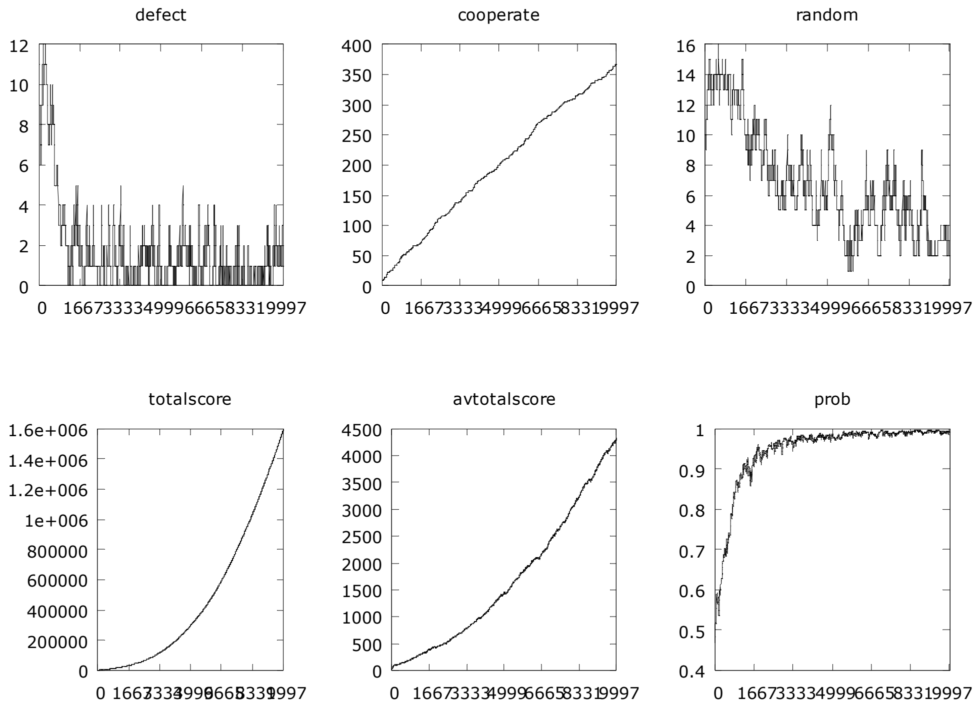


Figure 4.8: Dynamics of the Simulated Economy 4

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

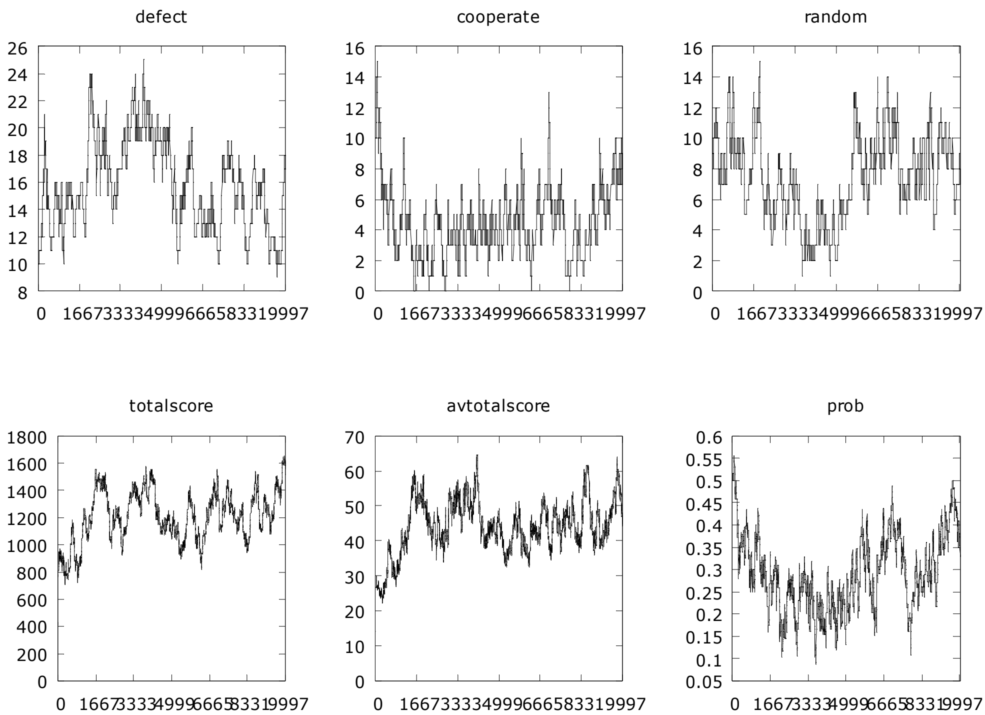


Figure 4.9: Dynamics of the Simulated Economy 5

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

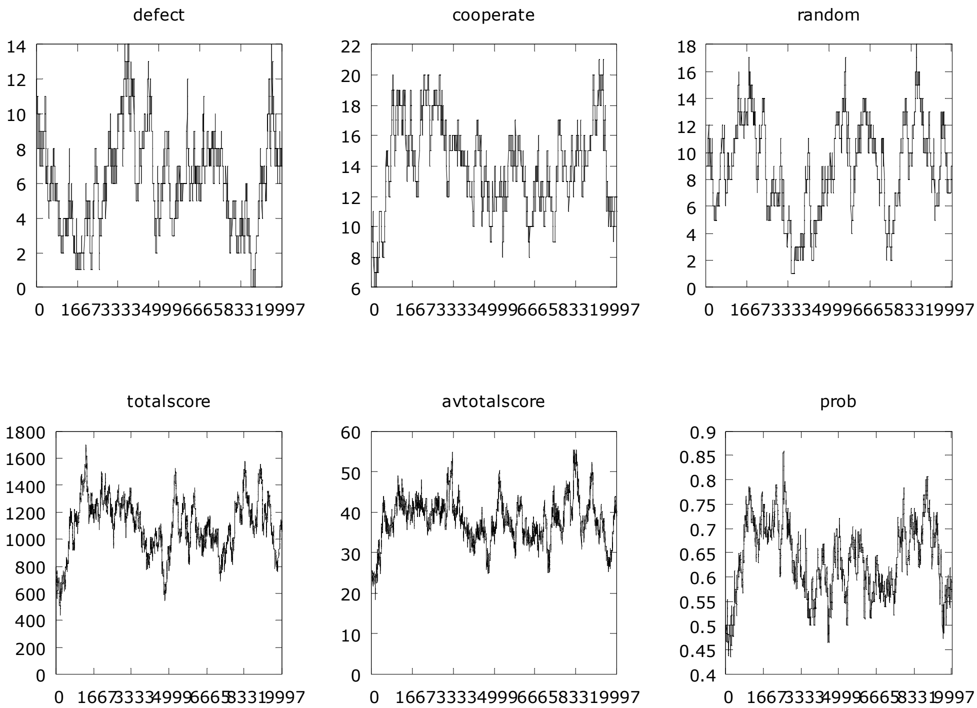
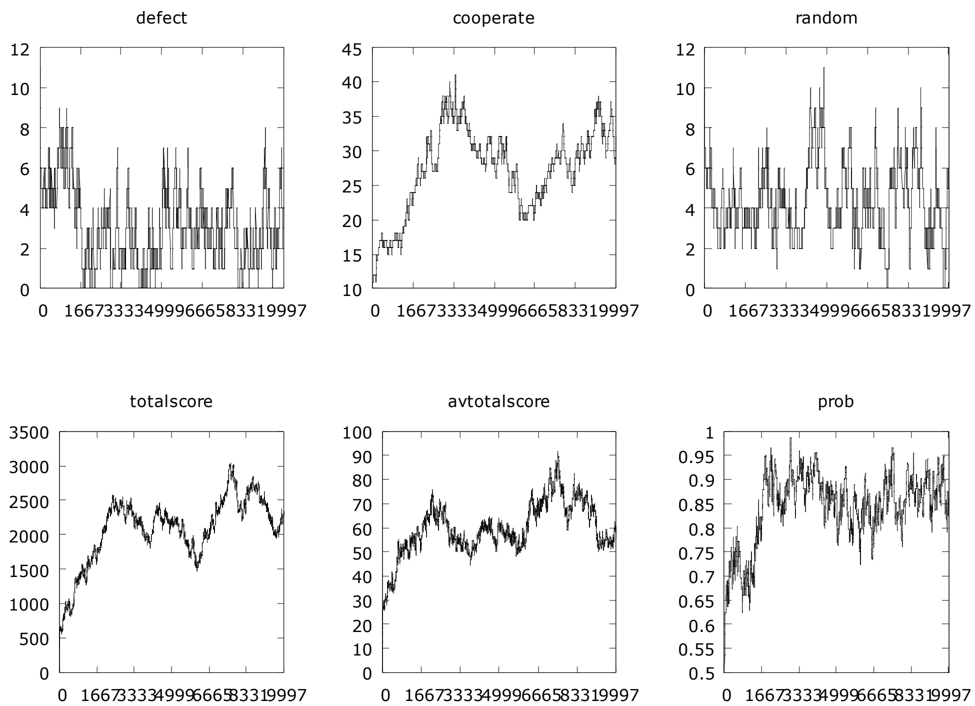


Figure 4.10: Dynamics of the Simulated Economy 6

(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 1,000 periods, a new enforcement mechanism is introduced and from that point on the external conditions are set in order to favor production against piracy. At this time, the average score of all the strategies is still growing and the predators' average payoff is about twice as high as the payoff of producers and random agents. However, its growth rates are gradually decreasing. Continuation of the same institutional setup will lead to stagnation and productive activities will be eliminated. Here, we abstract from cognitive aspects such as "How do they know that if they don't adopt any mechanism protecting producers they will face long-lasting stagnation?"[15] For simplicity, it is assumed that similarly to the external nature of the enforcement mechanism, its implementation is given. Then the resulting dynamics are explored.

In line with 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 a radical discontinuous change. In this case, at time 1,000 the detection probability jumps from 0% to 10%. In response to this change, non-cooperative predators face important losses. First they lose their wealth, and then 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 Figures 4.11 and 4.12, the average score falls from 231 to 179 in 100 periods because of the falling average score of agents playing "Defect" and "Random." The growth of producers' income that could compensate for this fall starts after the next 200 periods, around 300 iterations after the change. From that point on, both the average payoff of producers and their number gradually increase. The total average score slowly recovers. After 800 iterations following the institutional change, the average score exceeds its previous level (at the time of the change).

Clearly, the shift to an economy based on production is quite costly. The costs are distributed unequally and most of them are levied on predators, the former elites. One might object that this fall is not very realistic because it is a consequence of the rather simplistic assumptions of the model, namely, the inability of individuals to learn. On the other hand, learning and acquiring new knowledge takes some time, and at the organization level it is often a 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 the high number of iterations compensate for the lack of learning at the individual level.

The second institutional change was continuous. At time 1,000, a new rule was adopted and the detection probability was increased to 1%. After 100 iterations, the situation was repeated and the detection probability was increased again by 1% and so on 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 gradually decreases between periods 1,500 and 2,100. Later on, the trend reverses and the economy switches to a growing trajectory. At this time, it is 200 periods after the detection rate achieved the final rate of 10%, but at the same time the probability of cooperation exceeds 80%.

To sum up, the simulations of institutional change lead to similar qualitative and quantitative results as the previous simulations with fixed parameters. Moreover, they confirm our finding about the temporarily negative effect of enforcement.

15 This topic is extensively discussed in Mantzavinos (2001).

Figure 4.11: Discontinuous institutional change

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

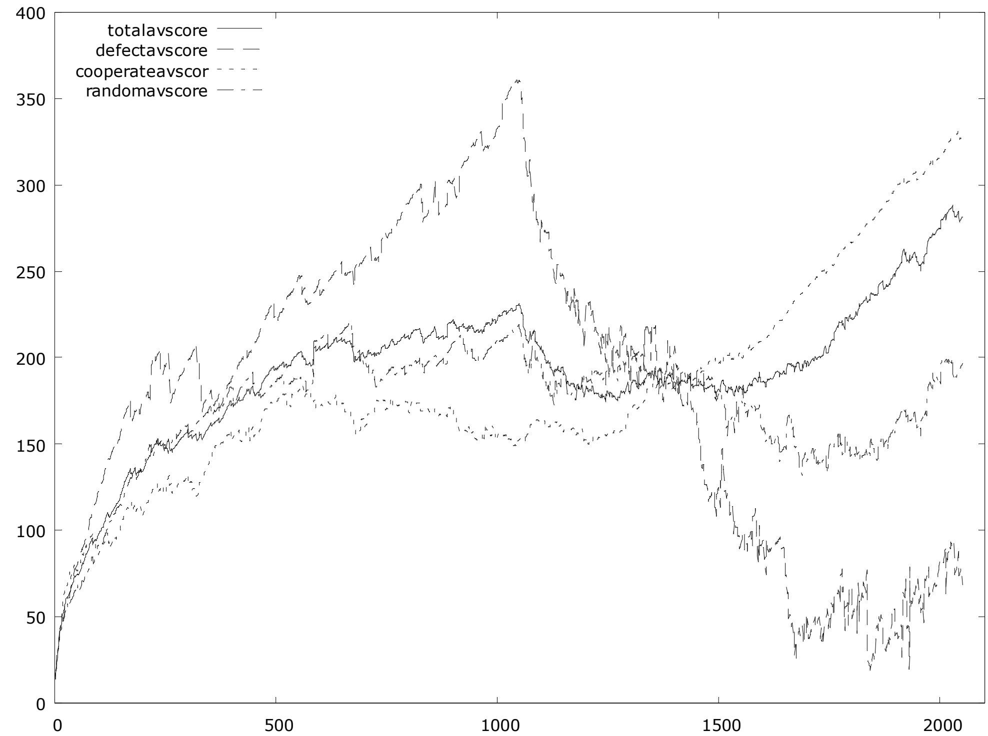


Figure 4.12: Discontinuous institutional change

Evolution of the share of cooperative behavior

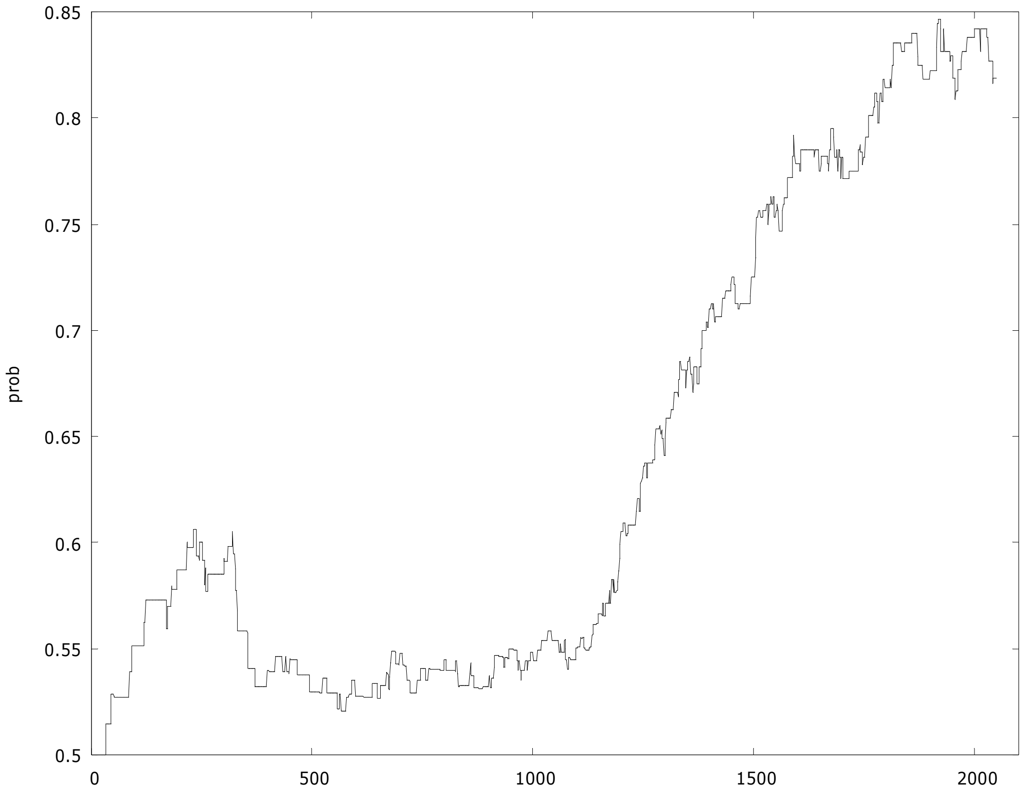


Figure 4.13: Continuous institutional change

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

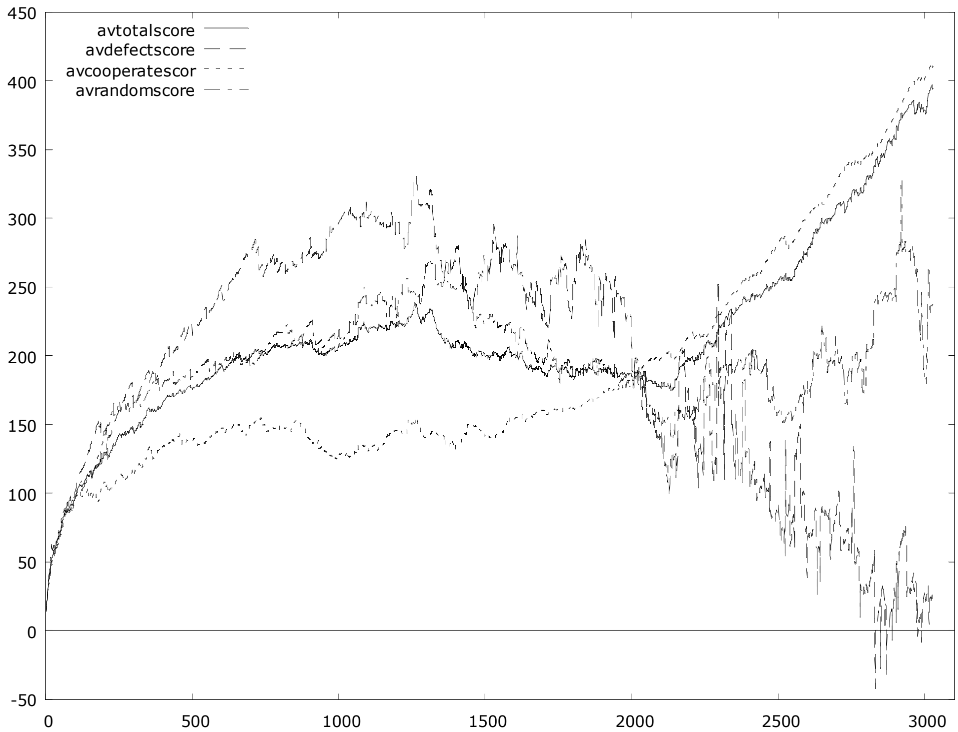
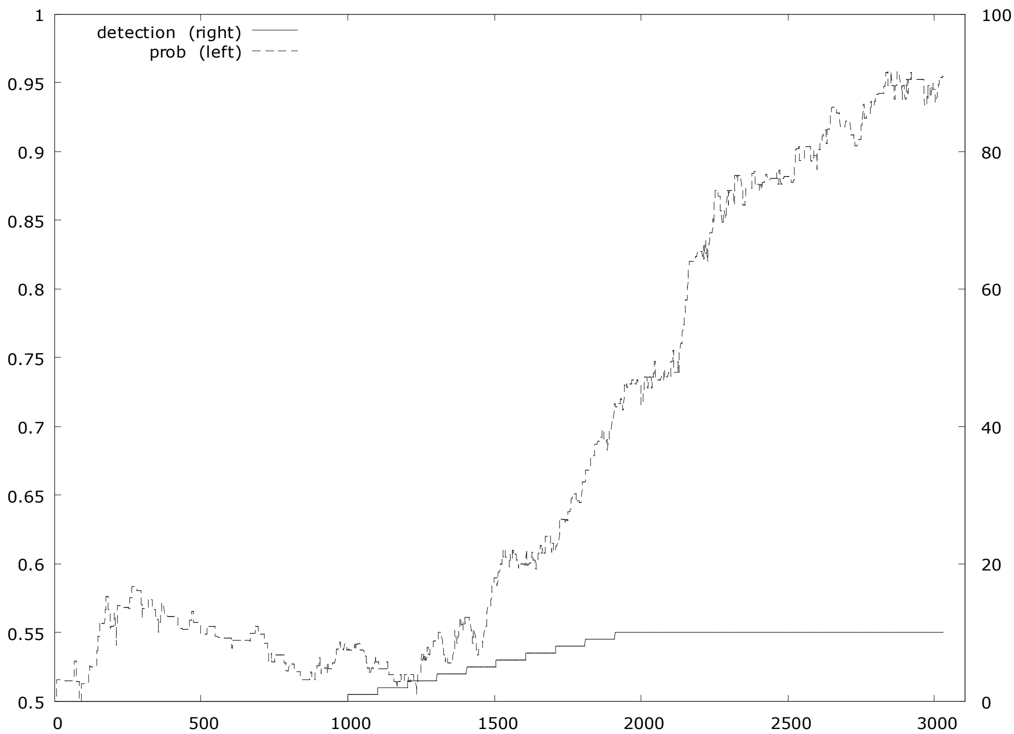


Figure 4.14: Continuous institutional change

Evolution of the share of cooperative behavior



5. Conclusions

It is well known that institutions can affect economic performance. Institutions favoring productive activities (in brief, cooperation) promote sustainable economic growth based on increasing productivity, whereas unproductive institutions giving high rewards to rent-seeking or other predatory activities lead to stagnation. The historical experience of many countries, such as Spain, Italy, Sweden, and, most recently, transition countries, tends to support this view.

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

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

This paper addresses these aspects of production and predation, economic growth, and institutional change explicitly within a framework of an agent-based economy. The main finding from the simulations is that no matter what 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 dominate predation, but without producers the income of the other agents stagnates. On the other hand, the worse the environment, the higher the need for cooperation for sustainable economic growth. 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 production attractive and persist over time.

The simulations also show that the effects of adopting such an enforcement mechanism are mixed. For low enforcement rates, the effect on income was even negative: the most successful agents were the predators and they were punished. Yet the number of cooperative opportunities, expressed as the number of producers, was still very low to generate income high enough to compensate for the predators' loss. These results occurred in the simulations where the ability to enforce cooperation was constant or time varying (simulations of institutional change caused by an external change in enforcement ability). Thus, the fears of change that might have been perceived by the 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 new agents. Nevertheless, the effect of the change on producers' income was positive right from the very beginning.

Appendix A: Simple Model of Predators, Producers, and the Effects of Protection

In this appendix we present the main ideas of a 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 elaborate versions can be found in Acemoglu (1995) and 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 toward various activities ranging from theft to rent-seeking. In fact, they try to acquire the output of others and their economic activity does not increase the overall welfare. Next, the producers invest their resources in production and protection of their product against the predators so that the marginal product of a unit of resources invested in each action is equal. Individuals of both types try to maximize their welfare. Therefore, in the optimum situation, 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 represent the fraction of time that is allocated for protection. Thus, the output produced in each unit of time equals $(1-f)$.

However, the predators cause some part of the output, L, to be 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 then be expressed as

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

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

$$[1-L(f,R)](1-f) \qquad (2)$$

and this payoff (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, a higher number of predators causes a 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 to expenditure 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 an individual predator (3) is decreasing if predatory behavior spreads among members of society.

$$(1-R)(1-f)L(f,R)/R \qquad (3)$$

In the optimum case, none of the groups has a higher payoff than the other. Thus, expressions (2) and (3) should equal. That is,

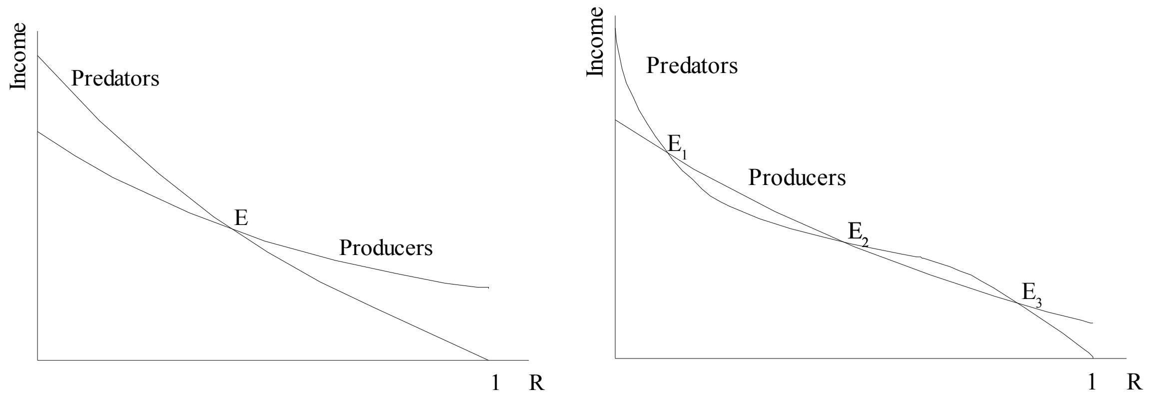
$$[1-L(f(R),R)][1-f(R)]=\frac{1-R}{R}[1-f(R)]L(f(R),R)\ . \qquad (4)$$

The assumptions about the loss function imply that producers' income (associated with the left-hand side of (4)) is decreasing in the fraction of non-cooperative predators R. This is because of a rise in the rent-seekers' population. It then causes producers to lose more of their income.[16] The predators' income, the right-hand side of (4), falls in R as well. Given our assumptions, the fraction of income of the predators increases less than proportionally with the rise of R. Furthermore, the increase of R induces a rise of f, hence higher protection costs cause a 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 time to production.

16 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 elaborate examples.

The situation is illustrated in Figure A1. It shows how the income of each producer and each predator changes with changes in the proportion of predators. The first case shows the situation with one equilibrium level *E* of *R* at which the returns to both types of behavior are equal. The predators' 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 fewer agents. As *R* increases, an individual predator gets lower and lower income up to the situation where there is no product to be preyed on.

Figure A1: Producers' and Predators' Incomes



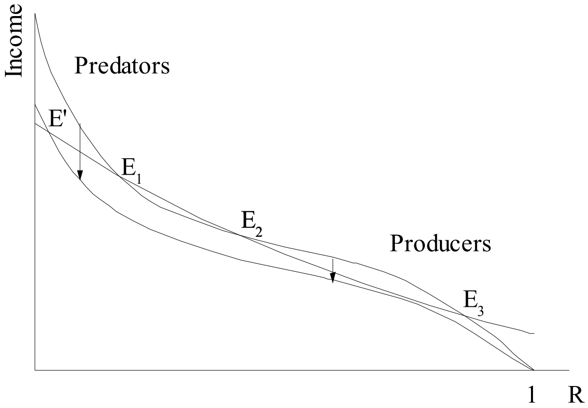
The second plot corresponds to the situation where multiple equilibria arise. Formally, this situation corresponds to a loss function that will increase sharply when the first predators occur, but the marginal increases of the loss then diminish. The three intersections of the two curves correspond to 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 to 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 afterwards the 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 a higher payoff than predators. However, if *R* exceeds the value corresponding to the second equilibrium, it converges to the inferior one with the lowest income, because the attractiveness of rent-seeking activities is again higher compared to production.[17]

As a matter of fact, in the case with multiple equilibria this model generates poverty traps because of its self-reinforcing mechanisms: an increased number of predators makes production less attractive and causes a further increase in predators. Moreover, a 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 the majority of society follows them. If not, these norms erode and are continuously abandoned by the rest of society due to pressures for conformity, social learning, and other factors. The effect of enforcement is illustrated in Figure A2. 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 the existence of such a probability of detection keeps the loss function and the function of producers' payoff untouched. Hence, only the expected payoff of predators decreases, which moves the productive equilibrium to the left, to higher income. After the enforcement mechanism is adopted and ready to use, either the location of the second two equilibria shifts to the right, or they diminish, as shown in Figure A2. This effect depends on the specification of the loss

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

function.

Figure A2: Effect of Enforcement Mechanism Adopted



Appendix B

Numerical summary of Figures 1 and 2							
Energy from environment = 2.5							
	mean	min	Q1	median	Q3	max	n
d0	39.853	29.565	34.814	40.887	43.874	52.047	(n=30)
d1	36.132	24.359	31.575	35.976	41.124	45.089	(n=30)
d2	36.854	24.519	31.713	34.79	42.559	60.842	(n=30)
d3	35.014	25.423	30.556	33.117	38.858	49.333	(n=30)
d5	37.616	24.615	32.751	35.565	42.421	57.192	(n=30)
d10	57.823	44.012	54.001	57.938	61.2	69.266	(n=30)
d15	92.109	54.798	63.532	70.644	82.564	502.5	(n=30)
d20	157.34	68.833	83.067	93.77	126.6	1107.7	(n=30)
d25	375.49	77.625	101.08	222.02	577.4	1495.9	(n=30)
Energy from environment = 5							
	mean	min	Q1	median	Q3	max	n
d0	288.92	201.29	265.37	282.35	313.41	408.89	(n=30)
d1	479.24	205.36	233.01	261.61	307.54	2604	(n=30)
d2	1925.2	1455.6	1699.6	1918.5	2157.3	2382.4	(n=30)
d3	2255.1	1933	2104.9	2226.4	2373	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	(n=30)

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