Iterative Method for Distribution of Capital in Transparent Economic System

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Abstract – In this paper, we propose an iterative method for distribution of capitals of investors between producers in a transparent economic system. This method allows each investor to take a decision with account of actions of other investors. Information about capitals of the community members is open. Investors and producers exchange information about their capitals, efficiency and intensions with the aid of light agent-messenger. It allows us to form a decentralized system of interactions in the economic community. We tested the model by means of computer simulations. The obtained results demonstrate efficiency of the proposed scheme of interactions.

Key words: investors, producers, competition, decentralized system, collective behavior, iterative estimation.

1. INTRODUCTION

Competition is an important part of a free market economy. Competition between economic subjects allows them to distribute resources of the system more effectively. At that, competition may be severe or softened. In this paper, we question is a collaboration between economic subjects profitable? In [1], R. Axelrod basing on the games theory and computer simulations showed that cooperating players gain. In resent papers [2, 3], V.M. Polterovich stressed an important role of cooperation between businesses pointing that "competitive mechanisms can be incorporated into institutes of collaboration." Also in [4, 5], authors analyzed forms of aggressive and constructive competition between individuals in the framework of the agent-oriented approach.

In this paper, we analyze an economic system consisting of producers and investors only. They can compete with one another. In the same time, they freely share information about their capitals including intentions of investors to invest their capitals in certain producers. In the papers [6, 7], Belgian scientists discussed a similar model where they used light agent-messengers to optimize operation of a production department and traffic routing in a city. In the same way in our model, we build a *decentralized* system of interactions of investors and producers who openly share information among themselves with the aid of agent-messengers.

Note that the authors of [8, 9] presented a close but in some way different interpretation of collective behavior of elements of a decentralized eonomic system. To solve a resource allocation problem they also used methods based on the games theory approach. In the framework of the active systems theory, this approach was proposed in [10, 11].

Contrary to the cited papers in our model, resources belong not to a single center but a whole community, where each of the participants commands its capital individually and an active investor is a resource owner. When choosing a producer for investment, resource owners take into account such characteristics as its *production efficiency* and the *capital* it owns. The key factor of our model is *economic transparency* of the system that is openness of information in the community. In what follows we discuss in detail an important question: the way in which exchange of information influences decision-making by investors. Inside the community, investors and producers exchange information by means of an interactive process and use agent-messengers (searching agents and intentional agents).

In other papers on multi-agent economic systems (see, for example, [12]) their authors analyzed a behavior of some groups of agents, however we discuss a simplified economic community consisting of investors and producers only. This is why we can develop and analyze our model rather fully.

1. DESCRIPTION OF OUR MODEL

In this section, we present the description of our approach to examination of behavior of the community of producers and investors.

2.1. General remarks

Suppose there is a community consisting of N investors and M producers, each of which has a capital K_{inv} and K_{pro}, respectively. We characterize each of the producers of this community by its production efficiency k_i. The investors and the producers are dealing in the framework of a *transparency economy*. The transparency of the system means that the investors and producers provide information about their current capitals, incomes and intensions to all the members of the community. In particular, the producers inform about the values of their capitals and their efficiencies. In return, with this knowledge in mind the investors can form their intensions about investments in a given production, which are also open to the community. It allows all the investors to correct sizes of their investments depending on the intensions of the other investors. We suppose that all the information open to the community of investors and producers is reliable. This means that when exchanging information about the sizes of their capitals and their intensions all the members of the community provide accurate records. In what follows we use computer simulations to show that sharing of information is profitable for the investors and producers.

We suppose that there are periods of action of the community of the investors and producers. For example, each a period number T is equal to one year. To be more precise in what follows, let us clarify two terms we use. They are *period of time* T and *iteration* t. We divide our timescale into periods of action of the agents $T = \{1, \ldots, N_T\}$, where N_T is the whole quantity of the periods. Inside of each period we perform a series of iterations that we denote as $t = \{1, 2, \ldots, t_{max}\}$, where $t_{\max}$ is the maximal number of iterations inside the period.

In our model investors and producers exchange information with the aid of agent-messengers similar to those used in paper [7]. There are two types of agent-messengers: *searching agents* and *intentional agents*.

Let us describe iterative process we perform between two periods $[T-1, T]$. At the beginning of the period *T*, the investors make their contributions into the producers they selected at the end of the previous period $T - 1$. At the end of the period $T - 1$, we perform a series of iterations that result in decisions of the investors about their investments during the next periods *T*. At the first iteration, each investor directs searching agents that gather information about all the producers, estimate possible dividends and choose *m* the most profitable producers among them ($m \leq M$). Next, each of the investors send intentional agents that inform the producers about contributions planed by the investors. Taking into account intentions of the investors, the producers estimate their capitals once more. At the next iteration, they inform searching agents about sizes of their capitals *with account of all possible investors*. Consequently, the potential profits of the investors and producers change. At that stage, the investors influence on another however not directly. They exchange information through the manufacturers. After sufficiently large number of iterations, investors arrive to final decisions about their contributions into producers for the next period *T*. These contributions are equal to the contributions planed after the last iteration. Notice that the agent-messengers make no calculations. They only gather and transfer information inside the community.

At the end of each period, the producers distribute part of their incomes between the investors in proportion to their contributions. If a capital of an investor or a producer becomes less than the minimal thresholds Th_{min_inv} or Th_{min_pro}, respectively, this investor or producer terminates its activity. However, if a capital of one of the investors or producers becomes larger than maximal thresholds Th_{max_inv} or Th_{max_pro}, respectively, such an investor or producer creates an “offspring”. At that, the “parent” gives to the offspring a half of its capital.

2.2. Mechanisms of distribution of investments and forms of profit function

Suppose that before the beginning of the period *T* the *i*-th producer has its own initial capital C_{i0}. The investors add their contributions to the capitals of each producer. We suppose that the *i*-producer invests all the available capital C_i it has at the beginning of the period *T*:

$$C_i = C_{i0} + \sum_{j=1}^{N} C_{ij} \, , \tag{1}$$

where C_{ij} is the capital invested by the *j*-th investor in the *i*-th producer at the beginning of the period.

The dependence of income of a producer on its current capital $Pr_i(C_i)$ has the form:

$$Pr_i(C_i) = k_i F(C_i), \quad (2)$$

where the profit function F is the same for all the producers, and the factor k_i characterizes the production efficiency of the i-th producer. At the end of each period the values k_i are varied randomly.

We analyzed three types of the profit function. They are linear, linear threshold and nonlinear functions. The linear profit function is

$$F(x) = ax, \quad (3)$$

where a is a positive parameter ($a \geq 1$).

The linear threshold function has the form

$$F(x) = \begin{cases} ax, \text{if } ax \leq Th \\ Th, \text{if } ax > Th \end{cases}, \quad (4)$$

where a is a positive parameter ($0 < a \leq 1$), Th is a threshold of the function $F(x)$.

The nonlinear function $F(x)$ has the form

$$F(x) = \frac{x^2}{x^2 + a^2}, \quad (5)$$

and again a is a positive parameter ($a \geq 1$).

At the end of a period T, the producers return to investors the capitals they contributed. Moreover, producers pay back to investors a part of incomes they earned. At that, a share of the j-th investor is proportional to the sum it invested into a given producer:

$$Pr_{ij} = k_{repay} Pr_i(C_i) \frac{C_{ij}}{\sum_{l=1}^{N} C_{il}}, \quad (6)$$

where C_i is the current capital of the i–th producer at the beginning of the period, k_{repay} is a parameter characterizing a share of payments of the profit to the investors: $0 < k_{repay} < 1$. The producer itself receives the rest of its profit that is equal to

$$Pr_{ij} = k_{repay} Pr_i(C_i) \frac{C_{ij}}{\sum_{l=1}^{N} C_{il}}, \quad (7)$$

2.3. Scheme of iterative process for decision making by investors

Let us describe in detail our iterative process during which the investors choose the producers for their investments. This process is as follows. *At the first iteration* the investors send searching agents to all the producers and define what capital has a producer at a time. At this iteration, a particular investor does not take into account contributions of the other investors. Then investors estimate values A_{ij} characterizing an expected profit from the *i*–th producer during the period *T*. The values A_{ij} are equal to

$$A_{ij} = k_{dist} Pr_{ij} = k_{dist} k_{repay} k_i F(C'_{i0}) \frac{C_{ij}}{\sum_{l=1}^{N} C_{il}}, \tag{8}$$

where C_{il} is the capital the *l*-th investor contributed to the *i*-th producer, C'_{i0} is a supposed initial capital of the *i*-th producer at the beginning of the next period (without taking into account contributions of the other investors); and $k_{dist} = k_{test}$ or k_{untest}, $k_{test} > k_{untest}$. Positive parameters k_{test}, k_{untest} define degrees of belief of an investor to a tested and untested producer, respectively. They take into account that the investors would prefer choose the producers they are tested. In the course of computer simulations we set $k_{test} = 1$, $k_{untest} = 0.5$.

Then each investor ranges all the producers in accordance with the values A_{ij} and chooses *m* the most profitable producers with large values of A_{ij}. After that, the *j*-th investor forms an intention to distribute all its capital $K_{inv\,j}$ among the chosen producers proportional to the obtained estimates A_{ij}. Namely, the *j*-th investor plans the value of the contribution C_{ij} that would be invested into the *i*-th producer:

$$C_{ij} = K_{inv\,j} \frac{A_{ij}}{\sum_{l=1}^{M} A_{lj}}. \tag{9}$$

Formally, for not chosen producers we formally set $A_{ij} = 0$.

At the second iteration, each investor uses intentional agents to inform the chosen producers about the size of capital it plans to invest in each of them.

Basing on these new data, the producers again estimate their *new initial capital* C'_{i0} they hope to have after the contributions of all the investors. Then each producer can form an estimate of the sum $\sum_{l=1}^{N} C_{il}$ and a new estimate of its capital according to equation (1).

Then the investors again send their searching agents to all the producers and estimate new capitals C'_{i0} of the producers and the sums $\sum_{l=1}^{N} C_{il}$ taking into account the intensions of other investors. The investors estimate their expected profits according to Eq. (8) where now they take into account the sum of the intended contributions of all the investors. After that each investor ranges the producers and according to Eq. (9) plans to distribute its capital proportional to the *new estimates* A_{ij}. The investors again send their intension agents to inform the producers about sizes of their planed contributions.

After sufficiently large number of iterations, they stop and each of the investors arrives to a final decision about its contributions for the next period T. These contributions are equal to the values C_{ij}, defined by the investors at the last iteration.

At the end of each period T the producers recalculate the capitals taking into account their amortization (for example, it may be amortization of equipment of producers): $K_{pro}(T+1) = k_{amr}K_{pro}(T)$ where k_{amr} is an amortization factor ($0 < k_{amr} \leq 1$). Investors take into account their expenses in the same way (for convenience, the corresponding values will be called an inflation factor) and recalculate their capitals: $K_{inv}(T+1) = k_{inf}\ K_{inv}(T)$, where k_{inf} is the inflation factor ($0 < k_{inf} \leq 1$).

3. ANALITIC TREATMENT

Let us examine two important questions. First, is it possible to obtain an analytical solution? Second, what are the dependences of the capitals on time? To answer these questions we use the following approximation.

Suppose we have one generalized investor and one generalized producer. Capitals of the producer and investor are equal to x and y, respectively. We assume that the investor contribute all its capital to the producer. Then according the above description, we characterize the dynamics of capitals by the following equations:

$$\frac{dx}{dt} = k_1 F(x+y) - k_2 x \tag{10}$$

$$\frac{dy}{dt} = k_3 F(x+y) - k_4 y\ , \tag{11}$$

where $F(x+y)$ is a function characterizing the producer's profit, k_1 is a factor characterizing the producer's profit, k_3 is a factor characterizing the investor's profit, and k_2, k_4 are factors characterizing amortization and inflation, respectively.

Let us make one more simplification and set $k_4 = k_2$. After that adding Eq. (10) and Eq. (11) we have:

$$\frac{dz}{dt} = (k_3 + k_3)F(z) - k_2 z\ , \tag{12}$$

where $z = x + y$. In some important cases, we can integrate Eq. (12). In what follows, in our analysis we use the linear threshold function (4). If the function $F(z) = z$, then

$$z = e^{[(k_1+k_3)-k_2]t} \tag{13}$$

When the function $F(z) = A = const$, we have

$$\frac{dz}{dt} = (k_1 + k_3)A - k_2 z \quad . \tag{14}$$

Let us introduce $u = k_2 z - (k_1 + k_3) A$. Then

$$\frac{dz}{dt} = \frac{1}{k_2}\frac{du}{dt} = -u \ ,$$

and

$$\frac{du}{dt} = -k_2 u \ . \tag{15}$$

This means that u tends to zero, and z tends to a constant equal to $\frac{(k_1 + k_3)A}{k_2}$.

Consequently, we obtain that if $F(z)$ is a linear function, the total capital of the community increases exponentially or decreases exponentially for large k_2, or tends to a constant when $F(z)$ reaches the threshold.

Thus, we determined how the capitals of the investors and producers change in the approximation of one generalized investor and one generalized producer.

4. RESULTS OF COMPUTER SIMULATIONS

We examined the above-presented model with the aid of computer simulations. Numerical calculations allowed us to verify convergence of our iterative process for different forms of the profit function (*linear, linear threshold and nonlinear*). We analyzed the influence of the iterative estimates on the dynamics of the total capital. In this regard, we performed calculations with and without iterations. We also examined the influence of inflation and amortization rates on the processes we simulated. Additional calculations allowed us to find how much the role of our iterative estimation depends on the number of investors included in the model.

In what follows, we present the parameters we used in our simulations

- The total number of the periods: N_T = 100 or 500;
- The number of iterations in each period: $t_{\max}$ = 1, … , 50;
- The minimal thresholds of capitals of the producers and investors (if a capital became less than one of these thresholds, the producer or investor in question died of): Th_{min_pro} = 0.01; Th_{min_inv} = 0.01;
- The maximal thresholds of capitals of the producers an investors (if a capital became larger than one of these thresholds, the producer or investor in question divided): Th_{max_pro} = 1, Th_{max_inv} = 1;

– The initial numbers of the producers and investors: $N_{pro\_initial}$ = 50; $N_{inv\_initial}$ = 50;

- The maximal numbers of the producers and investors: N_{pro_max} = 100, N_{inv_max} = 100;

- The maximal number of the producers m to which one investor can contribute its capital: m = 100;

- The share of the profit of the producers payed to investors. Usually it was equal to k_{repay} = 0.6;

- The parameter of the function $F(x)$ defining the profit: a = 0.1 (for the linear and linear threshold functions) and a = 5 (for the nonlinear function);

- The characteristic value of random variation of the coefficients k_i that define the efficiency of the i-th producer: Δk = 0.01;

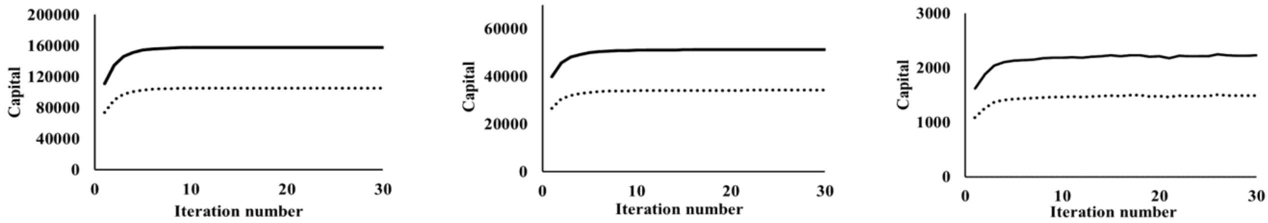
- The threshold of function $F(x)$: Th = 100 (for the linear threshold function).

At the beginning of our simulations, the factors k_i characterizing the efficiency of producers were random values uniformly distributed inside the interval [0, 1]. Also initially, the starting capitals of the investors and producers were random values uniformly distributed inside the interval [0, 1].

When one of the producers or investors divided, the "parent" gave a half of its capital to the "child". The "child"-producer inherited the efficiency of the "parent"-producer's k_i. The "child"-investor inherited the degree of belief of its "parent"-investor. The starting degree of belief to the "child"-producer we set equal to 0.5 since there were no contributions to it.

4.1. Convergence of iterative process

At first, let us examine the question of convergence of our iterative process for distributions of capitals. For the typical parameters and different profit functions, we verified the dependence of the final total capital of the investors and producers on the number of iterations in each period. The results for ideal environment without inflation and amortization we show in Fig. 1. We averaged the obtained data over 100 different simulations.



Linear function *F* — Linear threshold function *F* — Nonlinear function *F*

Investors ------- Producers

Fig. 1. Dependence of total capitals of producers and investors on number of iterations

We see that in all three cases our iterative process converges after 10–30 iterations. When we take into account inflation and amortization, the necessary number of iterations is larger. With regard to verification of the iteration convergence, in our simulations the numbers of iterations were equal to 30 or 50.

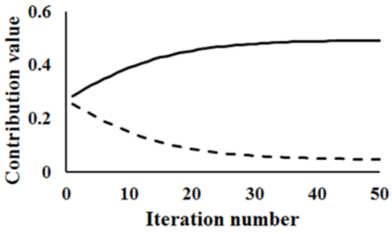
4.2. Results of simulations for linear profit function

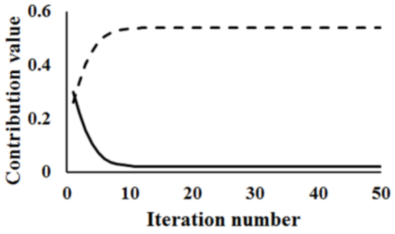
The simulations performed with the linear profit function (1) confirmed the conclusions of our analytical analysis. When using the linear profit function the total capitals of both the producers and investors either increase exponentially or decrease exponentially under conditions of high inflation and amortization.

4.3. Results of simulations for linear threshold profit function

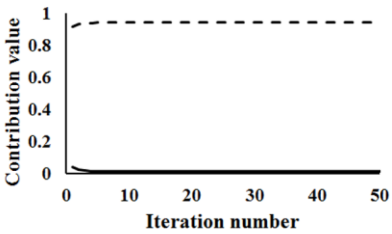
To show clearly how the iterations work, let us consider the case of two producers with a linear threshold profit function. We suppose that the capitals of these producers are the same and equal to 0.25 units, and the production efficiencies of the first and the second producers are equal to 0.5 and 0.9, respectively. Let the degree of belief to the first tested producer is equal to $k_{dist} = 1$. The second producer at the beginning of the simulation is “untested” and its degree of belief is equal to $k_{dist} = 0.5$. Let the number of investors be equal to $N_{inv\_initial} = 50$. Initial capitals of the investors are random variables uniformly distributed inside the interval [0, 1]. In Fig. 2, we present the results of simulations for the investor number 1. Let us explain the obtained results. For $T = 1$ when the more effective second producer is not verified, the investor increases its contribution into a verified producer from iteration to iteration in spite of the fact that the efficiency of this producer is less (Fig. 2a). At the next period $T = 2$ the investor selected the second more effective (now verified) producer, and its contributions to the first producer decrease from iteration to iteration (Fig. 2b). Next, at the following periods nearly all its capital the investor contributes to the second more effective producer (fig. 2c). The investor continues to invest into the second producer until the profit function of the second producer reaches the threshold ($Th = 100$). After that, the investor begins to contribute into the first producer increasing its contributions from iteration to iteration. In the same time, its contributions to the second producer decrease (Fig. 2d). For this case, we see that at first the estimate of the second producer was rather high since at the first iteration the investor decided to contribute the larger part of its capital to the second producer. However, with the increasing number of iterations the situation changes and the investor begins to contribute a part of its capital to the first producer.

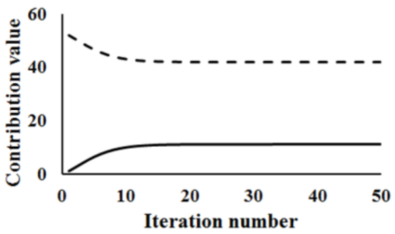
This means that for investor it is profitable to contribute in rising producers, which are producers whose profit increases with increase of their capital. In this process, iterations play an important role.





a) $T = 1$ b) $T = 2$



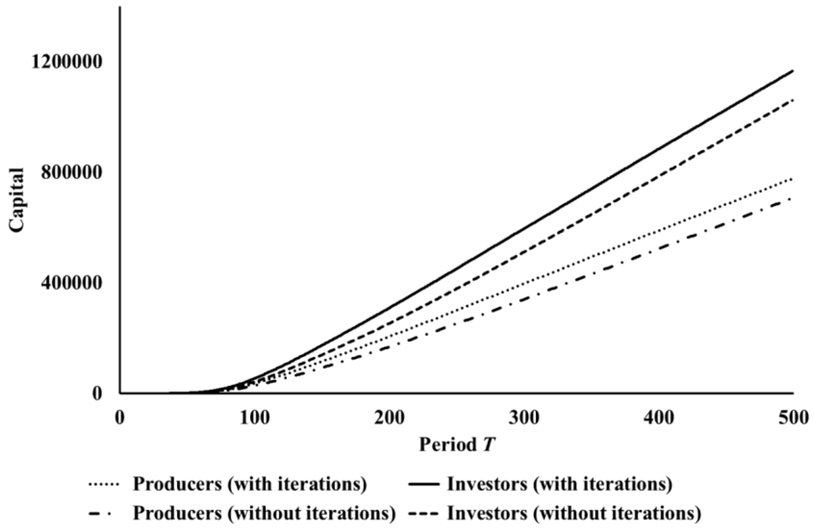


c) $T = 10$ d) $T = 75$

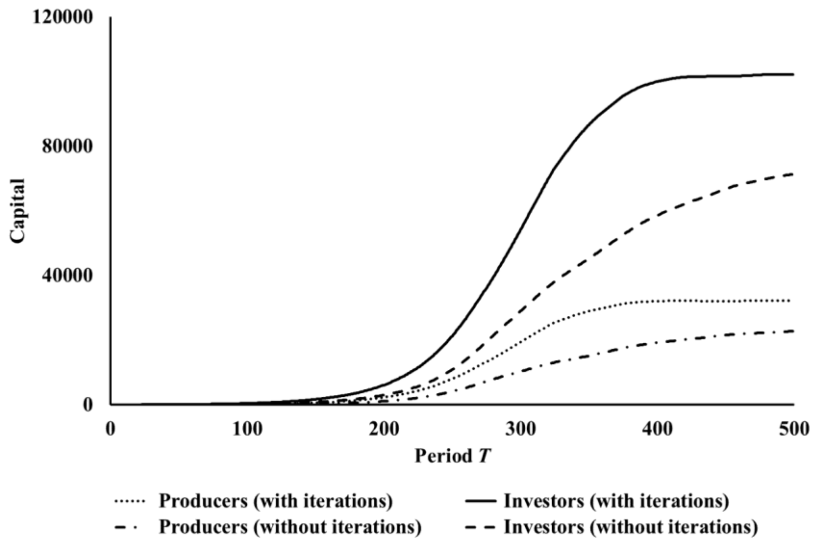
1-th producer 2-th producer

Fig. 2. Dependence of distribution of contributions of first investor on number of iterations and number of period T.

Efficiency of iterative estimates for the case $N_{pro\_max} = N_{inv\_max} = 100$. To show that an investor is more successful if it interacts with other investors (this means that it uses iterative estimates to determine the size of its contribution) we performed simulations with iterative estimates ($t_{\max} = 50$) and without them ($t_{\max} = 1$). We analyzed the cases with and without inflation. In Fig. 3, we present the results of these simulations.



a) Without inflation and amortization ($k_{amr} = 1$, $k_{inf} = 1$)



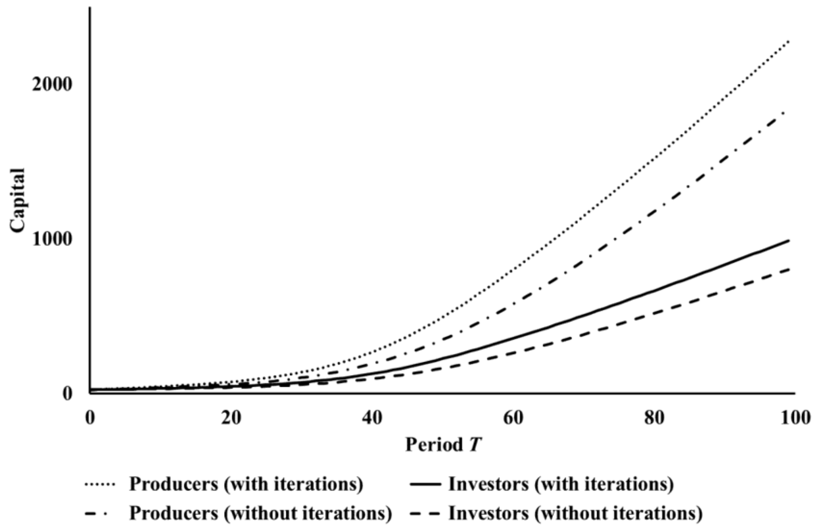
b) With inflation and amortization (k_{amr} = 0.9; k_{inf} = 0.95)

Fig. 3. Role of iterative estimates. Dependence of total capital of producers and investors on time

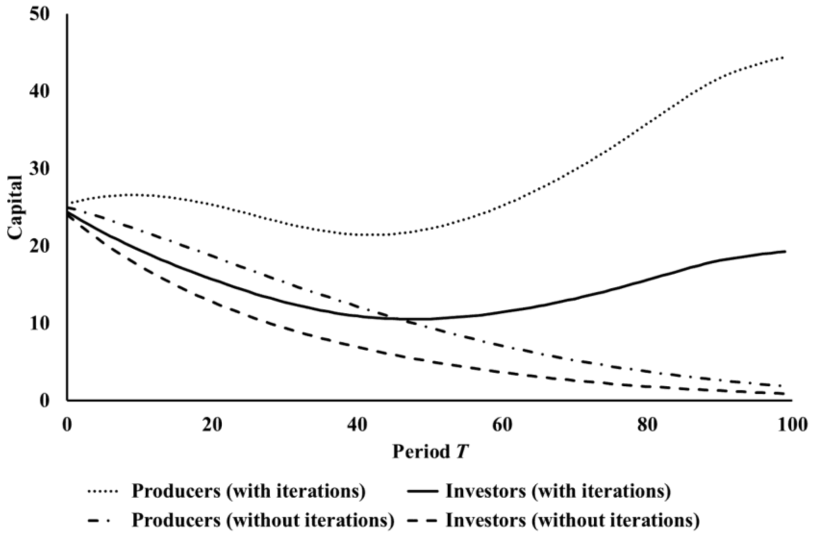
We see that success of investors and producers depend on the iterative estimates. In the course of computer simulations without inflation and amortization an increase of the total capitals of the community due to iterations was 10% (see Fig. 3a). When inflation and amortization are present, this influence is more important. Because of iterations, the total capitals of the producers and investors increase by 41-43% (Fig. 3b).

4.4. Results of computer simulations for nonlinear function

Let us analyze the results of computer simulations for a nonlinear profit function (5). These simulations were of the same kind as our simulations for linear and linear threshold functions described above. In the case of nonlinear profit functions, the computer simulations also confirmed the efficiency of iterations. In Fig. 4, we present our results averaged over 100 different simulations. We see that success of an investor as well as success of a producer depends on iterative estimates. At that, their influence is significant when inflation and amortization are taken into account (Fig. 4b), since without iterations ($t_{\max}$ = 1) capitals of the producers and investors decrease and the community ceases to exist.



a) Without inflation and amortization (k_{amr} = 1, k_{inf} = 1)



b) With inflation and amortization (k_{amr} = 0.95; k_{inf} = 0.95)

Fig. 4. Role of iterative estimates. Dependence of the total capital of producers and investors on time (a = 5; T = 100; m =100; Th_{max_inv} = Th_{max_pro} = 1; Th_{min_inv} = Th_{min_pro} = 0.01; k_{repay}= 0.3).

The performed simulations showed that our iterative process converged for all the examined profit functions. We demonstrated that when using iterations the investors distributed their capitals between the producers more effectively.

4.5. Influence of other factors

In addition to the presented results with the aid of computer simulations, we analyzed other factors influencing the process under consideration.

We examined the influence of the number of investors on the effectiveness of iterations. For example, when the number of producers was equal to two, we varied the number of investors. Fig. 5 shows the obtained results.

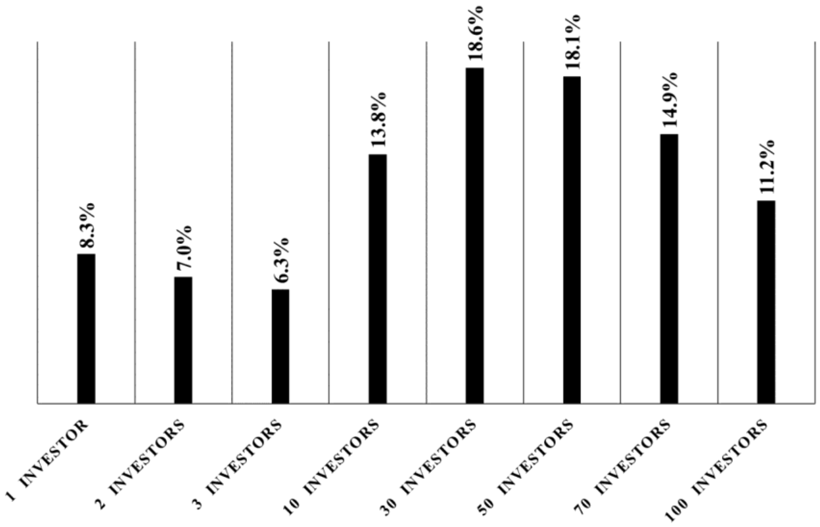


Fig. 5. Efficiency of iterations depending on number of investors in community

Comparing these results, we see that when for two producers the optimal number of investors lays in the interval from 30 to 50. The effect of iterations is of the order of 18%.

Varying the parameter k_{repay} we also analyzed the influence of distribution of the income between the producers and investors. Our results showed that if repays to the investors are small their total capital increased very slowly and became substantially less than the total capital of the producers. However, if the major part of the income went to the investors, we obtained a reversed situation. It is interesting that if a producer gives 60% of its income to investors, the total capital of the community is higher than when the share of the investors is equal to 50%. Thus, for all the community redistribution of the capital by investors is more profitable.

In addition, we analyzed the influence of inflation and amortization. The obtained results show that when inflation and amortization are high, the capital of the producers and investors decreases and they die. In the case of mild inflation and amortization at first, the total capital of the producers and investors increases, then it reaches its limit and the community comes to an equilibrium state. In the ideal environment without inflation and amortization, the capitals increase.

5. CONCLUSIONS

We developed and examined the model of the transparent economic system. The special features of this model are as follows: 1) collaboration between investors and producers, 2) openness of information about capitals and efficiency of producers as well as about intensions of investors to contribute to those or other producers, 3) iterative process using which investors come to decisions on the sizes of their contributions. In detail, we analyzed different types of profit functions and their influence on the iterative process. The most important result is the development of a new method of profitable distribution of capitals in a competitive environment through collaboration.

Thereafter we plan to analyze in more detail evolution of the community in question. For example, it is important to understand the behavior of the factor characterizing the efficiency of producers in the process of evolution. We also plan to introduce training of the investors by means of adjusting degrees of belief of the investors to producers. In particular, degrees of belief of investors to a producer can smoothly increase or decrease depending on their incomes. Consequently, in the process of training and interaction investors will form their own "opinion" about each producer.

It is possible that in future we will also use other similar methods of training and optimization [13-15].

Here we discussed a simplified economic community, but we hope that developing our model it would be possible to analyze processes close to examined here for real economic systems.

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