Using an Evolutionary Algorithm to Improve Investment Strategies for Industries in an Economic System

Vitaliy Kobets[1] and Maksym Poltoratskiy[1]

[1] Kherson State University, 27, 40 rokiv Zhovtnya st., Kherson, 73000 Ukraine

vkobets@kse.org.ua, max1993poltorackii@gmail.com

Abstract. Evolutionary investment strategies have been found to adapt distribution of investors' fund to technological changes of economic industries. In this paper we use evolutionary algorithm (EA) to improve investment strategies in economic system comparing shares of most profitable investors with other ones. Proposed algorithm selects an optimal combination of investment share in different industries for improving of investment performance. In our experiment we use statistical data from official sources to examine effectiveness of proposed investment strategy. We find the investment strategies using evolutionary algorithm to teach investors how to increase their profit as much as possible and obtain more profit than investor with best start possibilities.

Keywords. Evolutionary algorithm, industry, technology, input-output model, profitability

Key Terms. EvolutionaryAlgorithm, InputOutputModel, InvestmentStarategy

1   Introduction

Increasing the diversity of the population (investors' decisions) is achieved by means of evolutionary algorithm through discovery of investment share for all investors, except for the most successful one according to criterion of profit that encourages innovations in investment strategies. Reducing the diversity of the population by selecting the most successful investors according to the criterion of profit and fixation of their fund shares stimulates to a quality of investment strategies.

In the evolutionary metaphor *phenotype* is investor, *genotype* is set of investor's decisions (investor strategy means how much money is invested in an asset) (Fig. 1). Defining the best investment strategies using evolutionary algorithms takes place in the space of genotypes. Some phenotypic characteristics (share investment allocation between industries) are beneficial as they generate more profit. These features are rewarding for the progeny (investors' strategies of succeeding periods).

Solution of the problem for investors takes pace on the level of genotype. Population (set of investors) is the basic unit of evolution, i.e. population develops

rather than investors. Selection operators affect the set of investors. Variation operators act on the level of individual investor.
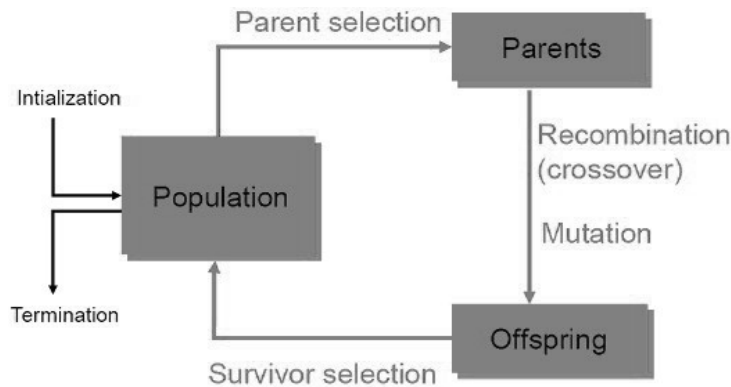
Fig. 1. Evolutionary selection of investment strategies

Evolutionary selection: (i) gives the best investors a better chance to increase their own profit (start the next year with growth of wealth) and   not to become bankrupt; (ii) moves the set of investors to better off technological adaptability.

Evolutionary strategies are usually applied to numerical optimization as a fast and good optimizer for real numbers with peculiarity of self-adaptability parameters through mutations [1].

The general problem is the effect of dynamics of technological coefficients on evolutionary strategies of investors in the economy. Basic input-output model for economic system has been developed by us, where the evolution of investment strategies depends on the variety of strategies, potential of industries and investors' fund. Numerical analysis shows how investors adapt their strategies to the changes of economic environment in order to increase their own profits. The question is how investors should change their strategy when there is uncertainty (there is a lack of data or volatility) as regards to a specific type of the dynamics of economic environment.

2   Economic Evolution in a Dynamic Environment

Evolutionary explanations and agent simulation are standard practice of research in economic sciences. Heterogeneity and cooperation of investors and their strategies are better treated by evolutionary agent model. An evolutionary model uses a set of agents for selection and changes. Evolutionary dynamics concerns behavioral interactions in evolutionary economics, which consists of several agents with heterogeneous economic strategies. We investigate how irregular and unpredictable dynamic economic environment changes the behavior of investors who make decisions in terms of such environments. Evolution in a changing environment does not occur when reaching equilibrium (steady state). Often it is more important not

only how *well* agents adapt i enough time, but how *quickly* they adapt to new challenges.

Environment variables include macroeconomic conditions, technological opportunities, economic policies and institutions (rules, procedures) and natural resources. Aspects of changes in environment's technology are: (i) how quickly they occur; (ii) how often (1 time per period).

The emergence of a dynamic environment usually leads to the fact that the system is no longer subject to analytical solution. Numerical simulations of multi-agent systems form an alternative to analytical approach, because it is much more flexible in the study of the behavior of the economic system. They allow to study the impact of set of investors and effects of dynamic environment on the formation of evolutionary strategies and their effectiveness. Different assumptions can be made about the selection factors and innovative mechanisms (random mutations of technological factors, deterministic trends for best investors, recombination of strategies) and bounded rationality of agents (habits, imitation) [2, 3]. Systems with *endogenous* variables (in contrast of exogenous ones) generate system with complex feedbacks.

Evolutionary algorithms are not sufficiently explored for the development, analysis and application of methods of solving problems in the economy [4]. The evolutionary approach allows us to make analysis and adaptation of an existing population (industries) to new environmental conditions, the algorithm implements the principle of adaptation and learning (fig. 2).
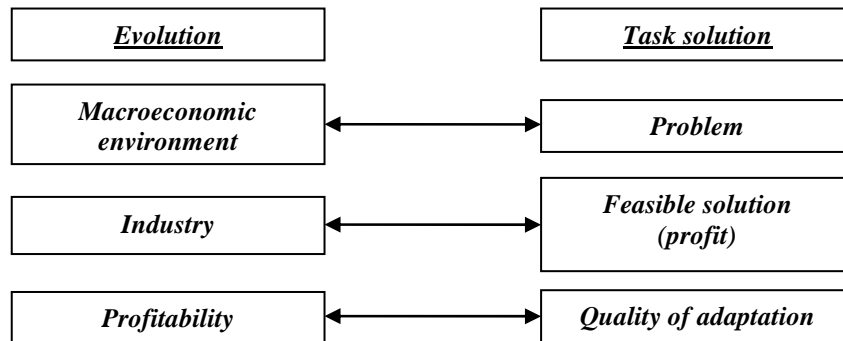
Evolution		Task solution
Macroeconomic environment	⟷	**Problem**
Industry	⟷	**Feasible solution (profit)**
Profitability	⟷	**Quality of adaptation**

Fig. 2. Correspondence of economic and evolutionary computation

Evolutionary algorithm (method) includes evolution strategies, genetic algorithms and evolutionary programming. In contrast of exact methods, evolutionary methods are approximations and allow for predetermined reasonable time to obtain high-quality solutions, which are very close to optimal and acceptable from a practical point of view [5]. Existing research do not consider investor's decision making using input-output model and evolutionary algorithms [6,7,8]. Thus we developed our own general model to compare how profit maximization strategies of investors adapt to technological changes.

The evolutionary agent model with initial conditions obtained through statistic data has been developed [9] describing a set of n economic industries (final demand and matrix of technological coefficients) and m investors, which are characterized by open exchange of information. Technological matrix coefficients are determined empirically for different industries. We identify the key variables for monitoring, such as (i) industry profitability, (ii) profit of investors, (iii) the share of investment fund distribution among industries for most efficient investors. Changing technology is reflected on the adaptive strategies of investors. Therefore, investors should diversify their portfolio from initial to the most profitable in an environment where technological change and the dynamics of resources may make a variation of production factors.

In the dynamic input-output model the investors form their individual evolutionary strategy, determining the direction of increasing their profits under technological changes. Their goal is to maximize their own profits. Investors prefer evolutionary strategies that generate more profit. Their rational capacity (possibility of predicting changes) and information for investment (priority selection industries) is limited. Investors have access to information about profits of other investors, profitability of all industries and investment shares, distributed by each investor between industries. Microeconomic information about private businesses is usually confidential, while macroeconomic information about industries is public.

Behavioral interaction determines how investors use accessible information to improve their evolutionary strategy through simulation of the most successful investors' behavior. The dynamics of the environment are outside the control of investors. Investors imitate the most effective investment portfolio, but how much it will increase their profit depends not only on the accuracy of information disclosed but on unpredictable dynamics of technological interconnection of industries within economic system. The dynamics of the environment is described by types of business cycle (table 1):

(i) **Kitchin cycle** is a short-term business cycle (40 months), when firms react to improvement of commercial situation by increasing their output through full employment using a fixed capital or decreasing of demand and increasing of stocks of products. Entrepreneurs need time to respond to this changing demand and materialize their decisions in the product. This cycle corresponds to final demand Y change.

(ii) **Juglar cycle** (7-11 years) means fluctuations of investment in fixed capital without changing the level of employment at fixed capital. Business cycles are driven by investments. It aligns to evolutionary strategies of investors in our input-output model.

(iii) **Kuznets swing** (15-25 years) relates with demographic processes, migration flows, reflects the demographic or infrastructure investment cycles. It corresponds to minor changes of technical coefficients in our input-output model.

(iv) **Kondratiev wave** (45-60 years) implies technological change, expressed by intervals of high growth of sectors and intervals of relatively slow growth. These waves conform to significant changes in the technological coefficients of our input-output model.

Table 1. Types of business cycles

Cycle type	Period (years)
Kitchin cycle (inventory, e.g. pork cycle)	3–5
Juglar cycle (fixed investment)	7–11
Kuznets swing (infrastructural investment)	15–25
Kondratiev wave (technological basis)	45–60

The paper **goal** is to develop new general model to compare how profit maximization strategies of investors adapt to changes in technological interrelations between industries under imperfect information by means of evolutionary algorithms.

3   General Model Characteristics

Consider a set of investors, each of them having a goal to achieve a higher level of personal welfare. Each investor may in turn invest his money in a finite number of industries. The procedure for allocation of funds by investor defines his investment strategy. Once the funds are invested, they can not be moved between sectors within one time period (year).

Agents understand the existence of a causal link between the investment strategy in the current period and the profit in the next period, but they can not use a calculation to find an investment strategy that maximizes their profit level. Instead, agents use the evolutionary search method, borrowed from nature: they expand their investment strategies by simulating the most successful strategies for investors as amended. Because investor prefers higher profits to lower ones he imitates two most successful investment strategies in this industry which bring higher profit than he has. Imitation is imperfect as describing the behavior of the investor with bounded rationality. Changes implemented during simulation ensure diversity in the pool of investor strategies and maintain the evolutionary search in action. The investor chooses the strategy of other investors, based on the characteristics (phenotype), indicating its effective ongoing performance and imitate his investment strategy with variations.

In this model growth of investment can be caused by increasing the efficiency of economic industries by reducing of technological coefficients (which corresponds to decrease in average cost of product in industry) due to technological progress.

The **task** of investor is to determine what share of his fund each investor should invest in the industries of economic system in a current period to get the maximum profit on the assumption of uncertainty as regards the next period.

Since investors do not invest their funds $I_{kj}^{(t)}$ in the industries (if any) with non-positive profitability, the sum of all shares of investment for each investor will be less or equal to one. Not all investment funds invested in the industry can give return in the next period due to imperfect information as regards next year's technological coefficients, therefore planned share of investments $d_{kj}^{(t+1)}$ may differ from the actual one.

Perfect information suggests that technologies are static or investor knows for sure in which direction and what exactly quantitative changes occur in technological dependencies between industries. In general it is unknown. Thus under imperfect information and bounded rationality (inability to process all available information to make rational decisions) each investor must adapt to changes, choosing as a standard the strategy of the most successful investor and, following it, seek to increase his own profit on his funds. This approach is an evolutionary metaphor that is used in evolutionary strategies for economic systems.

Investor adapts his current strategy depending on initial conditions (history). Profit function of each investor demonstrates which of the two strategies will survive and extend: either a leader strategy bringing the highest profit in the current period without changing investment shares, or follower strategy imitating the most successful strategies of other investors and changing his own investment shares.

Rational agent that imitates the strategy of the most successful investor seeks to reach same or greater profit under imperfect information. It leads to imitation by rational agent for the funds share of most successful investor and second best one in the current period. Criterion of strategy efficiency is the largest profit of the investor and the best (close to optimal) investment shares of most successful investors.

Strategies which used to be successful can lead to drop of investor's profit in the next periods. It requires adaptation of investors' strategies to new technological coefficients. To find the optimal investment level under unpredictable dynamics of industries, repeated numerical simulation with variable technology coefficients is applied and investors' profit is measured at the end of each simulation. After determination of highest level of profit we can prepare propositions for investment policy.

Numerical simulation is based on discrete, time-synchronized model, where profits and strategies of each agent are simultaneously updated at fixed time intervals. Each period t corresponds to one financial period (e.g., year). Each step of a simulation is divided into 2 separate renewal operations:

1) *economy update* – each agent invests his funds according to his evolutionary strategy taking into account the profitability of industries; profit is calculated for each investor;

2) *strategies renewal* – all agents compare their profit with other investors, and then agents simultaneously decide whether to imitate the strategies of other investors to change theirs.

Rules of evolutionary algorithms determine how a specific property (information) about effectiveness of strategies is distributed. These rules determine how participants exchange information in appropriate environments. The rules define the conditions of birth, death or survival of properties (information about directions and share of investment). The depth of influence h_{max} of history on current investment decisions should also be defined.

To describe the evolutionary algorithm for investors' strategies we apply variables and parameters presented in Table 1.

Table 2. Different approaches of interpretation the category "e-commerce"

Denomination	Variables and parameters
$d_{kj}^{(t+1)}$	capital share of investor k in industry j in period t
n	number of industries (constant)
m	number of investors (constant)
$I_{kj}^{(t)}$	capital of investor k in industry j in period t
$I_k^{(t)}$	total fund of investor k in period t
I_t	total fund of all investors in period t
$A_t = \left\{ a_{ij}^{(t)} \right\}$	technological coefficients matrix in period t
X_t	gross output of all industries in period t
$X_i^{(t)}$	gross output of industry i in period t
Y	final demand matrix for products of all industries (constant)
Y_i	final demand for product of industry i (constant)
$r_i^{(t)}$	profitability of industry i in period t
$\Pi_{kj}^{(t)}$	profit of investor k from industry j in period t
$s_{kj}^{(t)}$	undisposed fund of investor k that were planned for investment in industry j in period $t-1$ and are transferred as balance in period t
$S_{kj}^{(t)}$	total fund earned by investor k from industry j in period t

4   Algorithm of Investors' Strategies Adaptation to Changes in Technological Interdependence

The algorithm of adaptation of investors' strategies to changes of technological interdependence includes 8 steps (fig. 3):
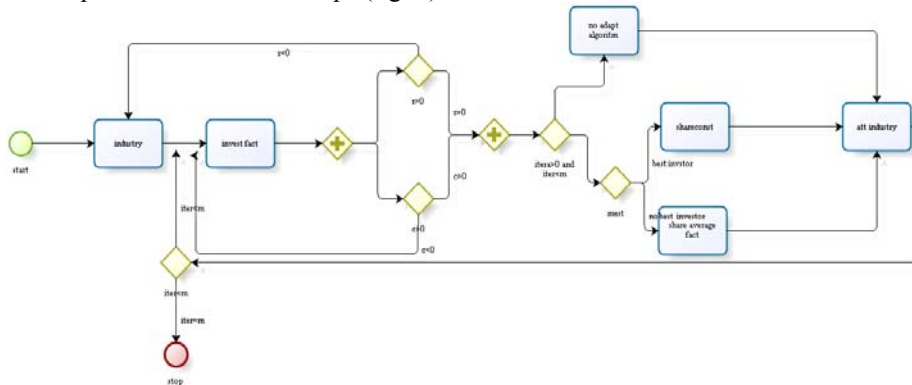
Fig. 3. Algorithm of adaptation of investors' strategies to technological changes

1. Initialization of industries

Economics system includes n industries. To analyze the investment attractiveness of industries in the initial period $t = 0$ we introduce technological coefficient matrix $A_0 = \left\{ a_{ij}^{(0)} \right\}$, $i, j = 1,...,n$, describing the relationship between all industries and the matrix of final demand Y for products of all industries.

2. Calculation of gross output

By means of input-output model the gross output of each industry is calculated as $X_0 = (E - A_0)^{-1} \cdot Y$; and the gross output of the whole economy during the year $X_0 = \sum_{i=1}^{n} X_i^{(0)}$ is determined. Further through matrix A_0 we calculate profitability for each industry i : $r_i^{(0)} = 1 - \sum_{j=1}^{n} a_{ij}^{(0)}$.

3. Initialization of investors

There are m investors, their number does not change during all simulations. In the initial period, there is egalitarian distribution of all funds between investors, each of them has the same initial money fund $I_k^{(0)} = \dfrac{X_0}{m}$, $k = 1,...,m$ to form his own investment portfolio. The total fund of all investors $I_0 = \sum_{k=1}^{m} I_k^{(0)}$ equals gross output X_0 of the country. Each investor applies one strategy per period, the number of active strategies is the number of investors.

4. Initial investment distribution across industries

Each investor can invest all his fund in one or more industries. The vector of their investment strategies is non-negative. If several investors allocate the same sum, the right to priority investments is determined by a chance.

The richest investor begins investment and invests in the most profitable industry. First investing in most profitable industry the investor may invest no more than 50% of his fund (to prevent his dominance in the most profitable industries). Then second richest investor invests no more than 50% of his funds in this most profitable industry. Once all potential investors fill the most profitable industry *in full*, there comes the turn of second profitability industry to be invested by the investor who is next in size of his funds. Investors do not invest in non-positive profitability industries. The investment process will continue until funds of investors or potential for investment in industries is completed (in period $t = 0$ the second option is not fulfilled by assumptions of the model). Wherein $I_k^{(0)} = \sum_{j=1}^{n} I_{kj}^{(0)}$, where $I_{kj}^{(0)}$ is a fund of investor k in industry j in period $t = 0$.

5. Technological changes

In general, changes of technological coefficients are determined by replacement of one vector of technological coefficients by another one. Each vector is formed independently and randomly from a uniform distribution.

Changes in technological coefficients are characteristics of industries that depend on: - unreliable resources, such as biotic resources vulnerable to climate change (forest or fish); - reserves of reliable resources (iron or coal) that are known by the end of the decade or century; - technological changes or changes in human capital [2].

Technological innovations are guided by research and developments, the effects of which on technological coefficients are treated as environment dynamic, to which investors have to adapt. Some industries gradually change with low frequency (mining and manufacturing), others – gradually with high frequency (telecommunications and communications), some others - accidentally with low frequency (hotels and restaurants), the rest - by accident with high frequency (IT industry). Simulation mechanism has one free parameter - technological coefficients which are beyond the control of investors.

Low frequency changes are simulated by transition from one vector of technological coefficient to another every 50 years (Kondratiev long waves) which is characteristic for the industries when changes of production methods are not a driving force of innovation (fisheries). To model high frequency changes transitions begin every 3 years, in response to rapid Juglar business cycle. These rapid changes are characteristics of industries that invest powerfully in research and development (communications and telecommunications). Both Kondratiev wave and Juglar cycle are related with fund dynamics and technological restructuring, as opposed to simple changes in employment represented by a shorter Kitchin cycle [10].

For next period $t = 1$ each technological coefficient of matrix $A_0 = \{a_{ij}^{(0)}\}$ will randomly change from interval $p \in [\alpha; \beta]$, where $-1 < \alpha; \beta < 1$. As a result, we obtain matrix $A_1 = \{a_{ij}^{(1)}\}$, where $a_{ij}^{(1)} = (1 + \frac{p}{100}) \cdot a_{ij}^{(0)}$. Under unchangeable finish demand Y we obtain new gross output $X_1 = (E - A_1)^{-1} \cdot Y$. In general case $X_1 \neq X_0$. For investors it means that not all of the funds invested by them in industries in period $t = 0$ will bring them profits in period $t = 1$.

6. Calculation of investors' profits

For period $t = 1$ starting from the first industry investor who invested the largest capital in the industry is determined. The following condition is used to calculate the profit for largest investor (to be specific – the first) in the industry:

If $I_{1j}^{(0)} \leq \min(X_j^{(1)}; 0)$ (if investment of 1st investor does not exceed the gross output of the industry j)

then $\Pi_{1j}^{(1)} = r_j^{(1)} \cdot I_{1j}^{(0)}$

else $\Pi_{1j}^{(1)} = r_j^{(1)} \cdot \min(X_j^{(1)}; 0)$. (1)

For the next largest investors in the industry ($k \neq 1$):

If $I_{kj}^{(0)} \leq \min(X_j^{(1)} - \sum_{h \neq k} I_{hj}^{(0)}; 0)$ (if investment of k-th investor does not exceed the gross output decreased by previously invested fund of larger investors)

(2)

then $\Pi_{kj}^{(1)} = r_j^{(1)} \cdot I_{kj}^{(0)}$

else $\Pi_{kj}^{(1)} = r_j^{(1)} \cdot \min(X_j^{(1)} - \sum_{h \neq k} I_{hj}^{(0)}; 0)$.

Similarly we calculate profits of the other investors in the rest of industries. The objective function of investor in period $t+1$ of investor $k = 1,...,m$ for profitability in period t :

$$\Pi_k^{(t+1)} = r_1^{(t+1)} \cdot I_{k1}^{(t)} + r_2^{(t+1)} \cdot I_{k2}^{(t)} + ... + r_n^{(t+1)} \cdot I_{kn}^{(t)}, \ k = 1,...,m .$$

(3)

where $I_k^{(t)} = I_{k1}^{(t)} + ... + I_{kn}^{(t)}$ is exogenous (fixed) investment funds of investor $k = 1,...,m$ in period t that can bring returns in period $t+1$. Each period investor makes decision on distribution of this fund between various industries of economic system. So $I_{kj}^{(t)}$, $k = 1,...,m$, $j = 1,...,n$ is the fund from which the investor makes decision to invest in industry j in period t that can bring returns in the period $t+1$.

7. Determining the most effective investor

Imitating investor strategy changes, while imitated investor strategy (investor with highest profit) does not. The choice of agent strategy to be imitated depends on relative profit. Imitating investor always chooses the investor with the largest current profit. Only if the investor has no peers in profit value, he does not revise his own strategy. Imitation is the only mechanism affecting the change of agents' strategy. There should be *initial state* of income distribution between investors before evolutionary selection strategies. Real imitation is never without errors. Errors are called mutations in evolutionary theory. They are fundamental to the evolutionary process, because they create and maintain diversity in which selection can work [2].

As a result of calculating profit of all investors the investor who received the greatest profit is determined, then the shares of its investment to all industries is calculated: $d_{kj}^{(1)} = \dfrac{i_{kj}^{(0)}}{\sum_{j=1}^{n} i_{kj}^{(0)}}$, $j = 1,...,n$, where $i_{kj}^{(0)} = I_{kj}^{(0)}$ (when fund of investors is less than industry's potential), or $i_{kj}^{(0)} = \min(X_j^{(1)} - \sum_{h \neq k} I_{hj}^{(0)}; 0)$ (when industry's potential is less than investor's fund, $\sum_{h \neq k} I_{hj}^{(0)}$ - investment of all previous investors, except k). In general shares of investment will equal to:

$$d_{kj}^{(t+1)} = \frac{I_{kj}^{(t)}}{I_k^{(t)}} \text{ , де } \sum_{j=1}^{n} d_{kj}^{(t+1)} \le 1, \ k = 1,...,m, \ j = 1,...,n, \ t = 0,...,T \ . \tag{4}$$

The total investment for all investors in period t is $I^{(t)} = I_1^{(t)} + ... + I_m^{(t)} = \sum_{k=1}^{m} I_k^{(t)}$.

In next investment period the most effective investor will not change his strategy, which has brought him the greatest profit. He leaves unchanged his share of investment from all his wealth in the same industries and will distribute the remaining funds (if any) according to stage 4. Wealth of investor is the sum of his investment, profit from his investments and retained fund (if any).

8. Determining evolutionary strategy

The remaining investors with lower profit than the most efficient investor, try to achieve and eventually surpass the best result. To do this they apply the following evolutionary strategy:
1) they calculate shares of invested funds for all investors in all industries;
2) second largest efficient investor for each industry in which he has invested, defines two most successful investors in this industry by the profit criterion. Then he calculates the average share among these ones:

$$d_{kj}^{t+1} = \frac{d_{Bj}^{t} + d_{(B-1)j}^{t}}{2} \ , \tag{5}$$

where investors B and $B-1$ received the greatest profit in previous period after investing their funds in industry j . Evolution strategy is arithmetic mean, which also absorbs errors in the decisions of investors.

According to this evolutionary algorithm investor k for the period $t = 2$ invests in industry j sum $I_{kj}^{(1)} = d_{kj}^{(1)} \cdot S_{kj}^{(1)}$, where $S_{kj}^{(1)} = \sum_{j=1}^{n} (I_{kj}^{(0)} + \Pi_{kj}^{(1)} + s_{kj}^{(0)})$ is total sum of funds available to the investor k , where $I_{kj}^{(0)}$ - investments in industry j , returning to the investor in period $t = 1$, $\Pi_{kj}^{(1)}$ is a profit earned by investor k in period $t = 1$ and $s_{kj}^{(0)}$ - retained investment funds of investor k , for next period $t = 1$.

If only one investor invests in specific industry, then as the second share is taken 0, i.e. evolutionary share of investments will be half the size of previous share. Similarly, the evolutionary algorithm is applied to other industries. This algorithm is repeated for all other investors.

The Evolutionary Algorithm is described below (Table 3).

Table 3. The evolutionary algorithm for improving investment strategy

	Algorithm 1 Evolutionary algorithm for investors' strategies
1	Initialization of industries n
2	Evaluation of the initial gross output X_j and profitability of industries r_i, $i = 1, ..., n$
3	Initialization of investors m with initial funds $f_j = \dfrac{X}{m}$, $j = 1, ..., m$
4	Initial allocation of funds between industries
5	**while** $I_j > 0$ and $r_i > 0$ **do**
6	$\min(I_{kj} - \sum_{h \neq k} I_{hj}; X_j \cdot coef)$, $coef = 0.5$ for $t = 1$; $coef = 1$ for $t > 1$
7	**Endwhile**
8	Profit of investors
9	Change of technological matrix A_t
10	Actual distribution of investors
11	**while** $I_j > 0$ and $r_i > 0$ and $X_i > 0$ **do**
12	**If** $I_{kj} \leq \min(X_j - \sum_{h \neq k} I_{hj}; 0)$
13	**then** $\Pi_{kj} = r_j \cdot I_{kj}$
14	**else** $\Pi_{kj} = r_j \cdot \min(X_j - \sum_{h \neq k} I_{hj}; 0)$
15	**end while**
16	**Selection of most profitable investor**
17	**if** $\Pi_B = \max(\Pi_1, ..., \Pi_m)$
18	**then** $d_{kj} = const$
19	**else** $d_{kj} = \dfrac{d_B + d_{B-1}}{2}$

5   Experimental Results of Desktop Application

Desktop application *Investment Strategy* has been created specifically for simulating of experimental data for macroeconomic input-output model of this paper, using a graphical interface of $C^{\#}$ system libraries System.Drawing and System.Windows.Forms. Note that desktop application *Investment Strategy* shows results of two competitive strategies, such as leader, who do not changes his investment shares, and follower, who imitates strategies of two most efficient investors. Results are presented in tabs *Calculation*, *Profit Dynamics*, *Profitability Dynamics*, *Gini Index*. Fig. 4 shows the application window for 100 periods (corresponds to 100 years).

Investor with largest fund has privilege to invest in most profitability industries. If technological coefficient of matrix grow at average (it means that profitability de-

creases), than all investors except first almost have no chance by the means of evolutionary algorithm to be more effective than largest investor (fig. 4). During the experiment, the evolutionary dynamics of investment strategies is described by the following graphs (x-axis – time, ordinate is dynamics index):

1. Industries' profitability variation (after changes of technological coefficients).

2. Profit dynamics of investors to compare two types of strategies: the leader and imitators.

3. Gini coefficient (profit distribution between investors).

4. Dynamics of correlation coefficient between investment and profit of investors.

On fig. 5 for almost all experiment for any number of investors and investment periods all investors except first have no chances to be more effective than greatest one. In this case leader strategy is more effective than evolutionary algorithm for technological changes when average profitabilities of industries rise ($\alpha; \beta > 0$).
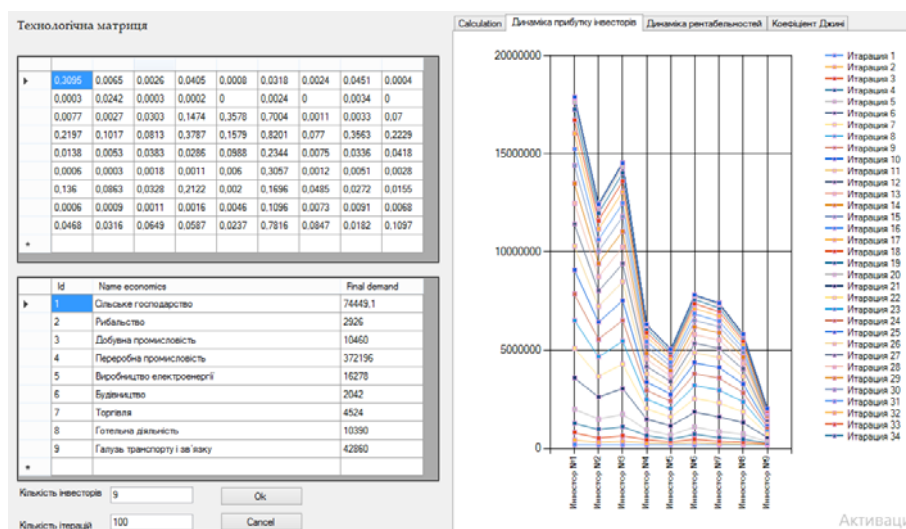

Fig. 4. Desktop application Investment *Strategy*

The more investors the more chances to achieve best results by another investor even technological coefficients increase (fig. 6).

Second investor became leader instead of first investor (fig. 6), that confirms efficiency of evolutionary algorithm for larger number of investors using profitability industry indexes (fig. 7).

On fig. 8 for prevail cases (both small and large number of investors) evolutionary strategies of investors are more effective than unchangeable shares of leader when average profitabilities of industries fall ($\alpha; \beta < 0$).
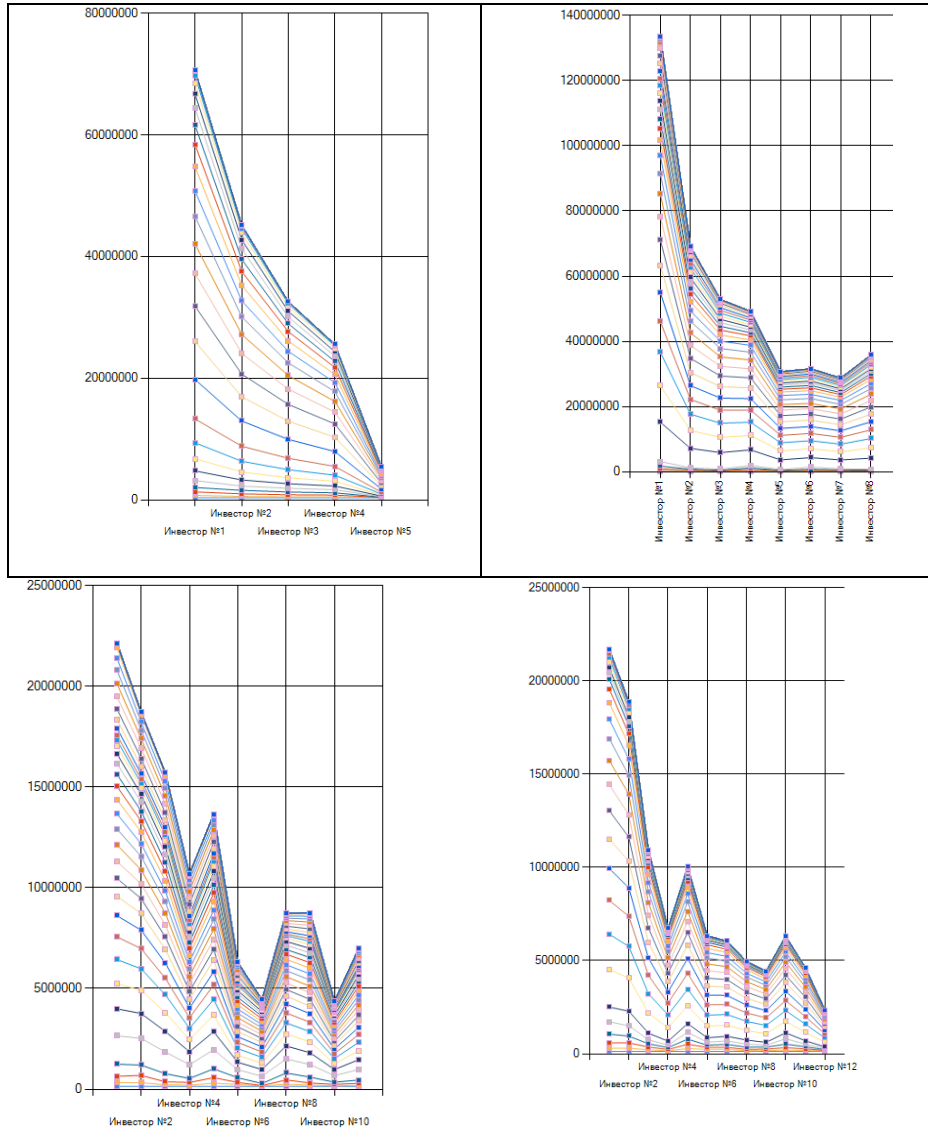
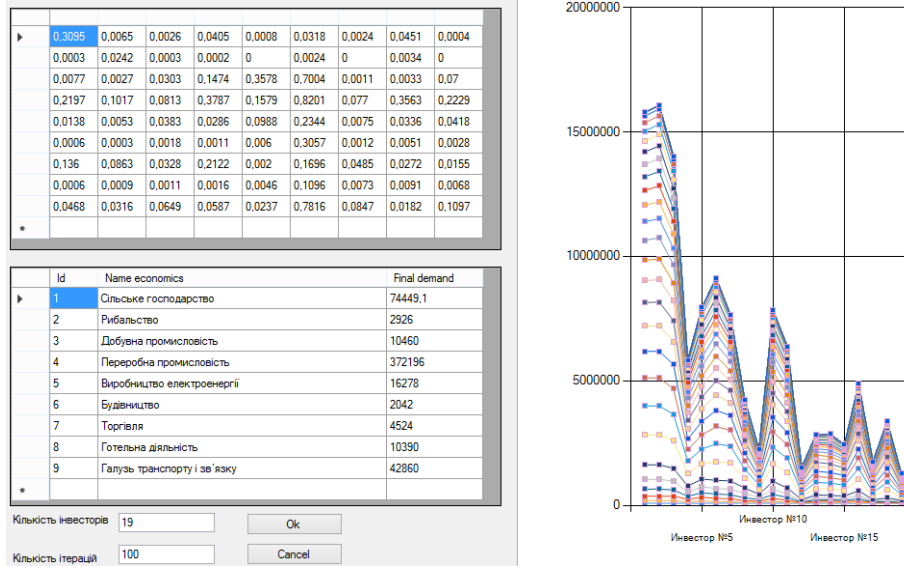**Fig. 5.** Effectiveness of leader strategy for 5, 8, 10 and 12 investors when technological coefficients rise

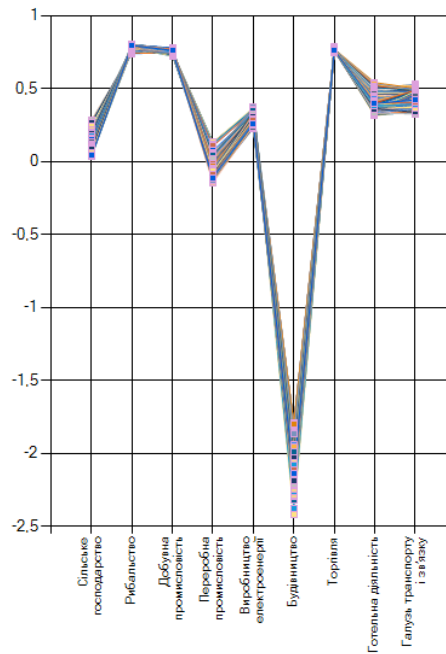**Fig. 6.** Effectiveness of evolutionary algorithm for 11 investors

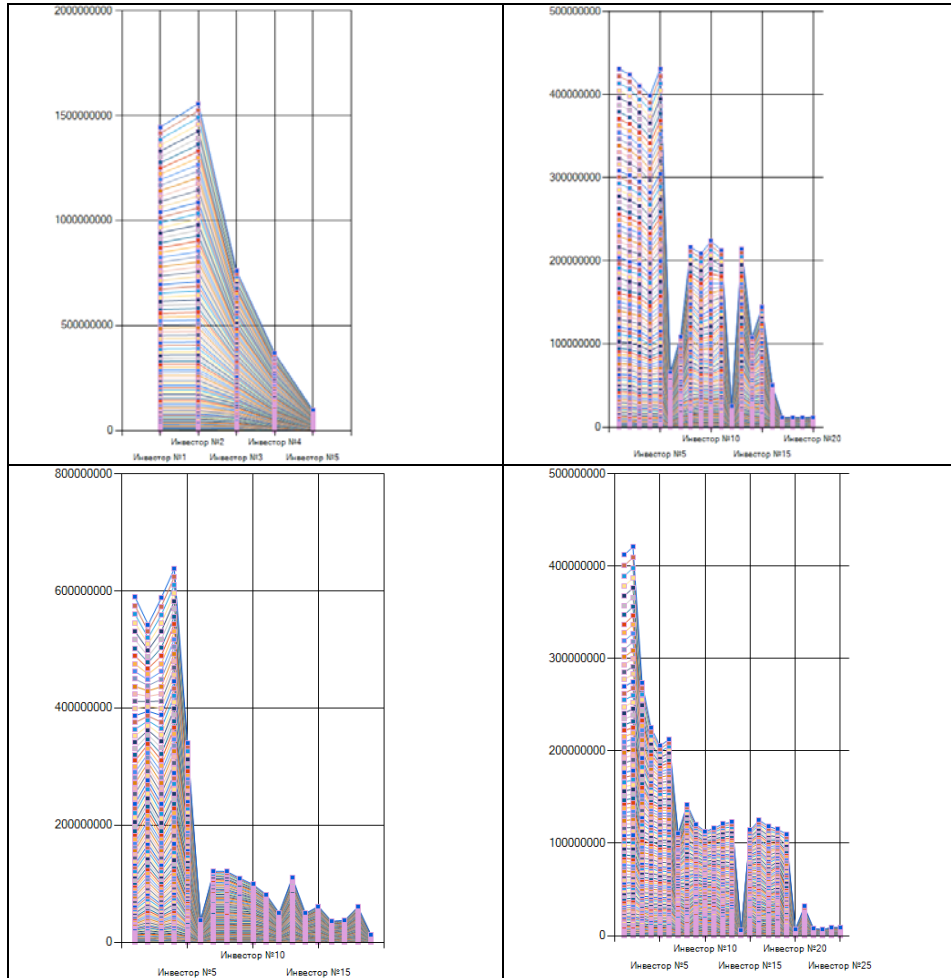**Fig. 7.** Dynamics of profitability industry indexes

Fig. 8. Effectiveness of evolutionary strategy for 5, 15, 20 and 25 investors when technological coefficients fall

6   Conclusions

Evolutionary investment strategies have been found to adapt distribution of investors' fund to technological changes of economic industries. In this research we use evolutionary algorithm (EA) to improve investment strategies in economic system comparing shares of most profitable investors with other ones. Proposed algorithm selects an optimal combination of investment share in different industries for improving of investment performance. In our experiment we use statistical data from official sources to examine effectiveness of proposed investment strategy. We find the investment

strategies using evolutionary algorithm to teach investors how to increase their profit as much as possible and obtain more profit than investor with best start possibilities.

Desktop $C^{\#}$ application *Investment Strategy* using a graphical interface with tabs has been created specifically for the numerical investigation of effectiveness of investment strategies using evolutionary algorithm.

As a result of our numerical experiment we have found that under increasing of technological coefficients effectiveness of evolutionary strategy is less than strategy of leader with unchangeable shares. In contrast under decreasing of technological coefficients effectiveness of evolutionary strategy is more than strategy of leader with unchangeable shares. The more investors the more effectiveness of evolutionary algorithm to improve investment strategies for industries of economic system

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