Computer Modeling of the Economy Dynamics of Ukraine, Taking into Account the Socio-Economic Clustering of Society

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Abstract

The object of the research is the economic dynamic of a depressed low-productive economy, as exemplified by the modern Ukrainian economy. With the purpose to analyze the main causes and consequences of such an economy, the characteristic tendencies of its functioning, activation of the processes of reformation and growth, there was developed the dynamic economic model with significant share of consumer import and export of raw materials, with the use of IT technology. The model also takes into account the socio-economic clustering of a society. It is formalized in the space of economic variables, which describes respectively the savings (liquid capital) of the main social groups involved in the economy, the prices of

consumer products in the domestic and foreign markets, the price of exported raw materials for the exchange rate.

The model is intended for qualitative analysis of the processes occurring in the economy described by it, and for conducting computational experiments on the basis of information technologies in simulation mode with its parameters, which allows to identify the most characteristic features of the object of the research. The results of experimental researches with the model allowed to establish the main periods of economic dynamics represented by the dynamic variables model, its specificity and social consequences for the society, which is characterized by a bimodal distribution of savings. There was investigation the dependence of the mode solution from it parameters which means in practice the dependence of economic dynamics from the change of individual conditions and factors of economic development.

The obtained results are important for informational and analytical support of decision making processes in order to bring the being studied economy out of a low-productive state

Introduction

The modern world economy is characterized by the intensity of economic ties and integration processes in general. These processes are inevitably affect the economic dynamics of each of the countries, including those that are not part of the integration unions, or their integration efforts are ineffective due to the low or very weak level of the development of national economy. The fact is that such countries are often included in the system of integration processes as raw appendages, in particular as the suppliers of cheap labor and the consumers of goods produced in highly productive economies (Toshkov, 2010). These negative phenomena are to a certain extent characteristic for Ukraine nowadays. In terms of GDP in 1990, Ukraine was the sixth largest in Europe (Hryhorkiv, 2015; Mikhalevich and Sergienko, 2005). Then it outperformed all transition countries, and now it has become a country with a depressed economy, low living standards and social security (wages of 1% of the most well-off workers are 43.3 times higher than the pay of 50% of the poorest workers (Eshchenko,

2018), with the largest decline compared to the economies of Germany, Japan, South Korea, which, at one time, were almost completely destroyed (Pauchok, 2013; Perevozova et al., 2019). A number of researchers have been studying the causes of such a situation, possible scenarios to overcome it and the transition to intensifying the processes of reform, stabilization and growth of the Ukrainian economy (Eshchenko, 2018; Savytska et al., 2022, 2023; World Economic Forum 2014). Different methodological approaches are used, among which one of the most promising is the modelling (Toshkov, 2010). Just modelling and more precisely, economic-mathematical modeling nowadays has become the most effective tool for the research of complex socio-economic phenomena and processes (Babenko, 2013, Blahun et al., 2020; Blahun, I.S. and Blahun, I.I., 2020; Buyak, 2012). Taking into account the powerful development of modern information technology we can argue that the application of this method in science has great prospects.

The purpose of this work is to construct the dynamic model of the Ukrainian economy which, firstly, took into account in a certain sense the socio-economic clustering of Ukrainian society, and secondly, reflected the specificity of the economy with significant share of export of raw materials and imports of consumer products (Dynkin, 2007; Hrabovskyi et al., 2020). The tasks related to this purpose are to formalize the model in an adequate way for the study of socio-economic indicators of space, to develop the appropriate software and information support for the constructed model and to use this model for computer-simulation research of the basic laws and peculiarities of the Ukrainian economy (Babenko et al., 2017; Malyarets et al., 2018). The establishing on IT-based calculations with the model of general tendencies of economic dynamics allows not only to confirm the known theoretical positions and facts about the investigated economy, but also to strengthen the analytical and informational base of systems of support for making real decisions in the economy.

Formalization of the model

To construct the dynamic model of economy of Ukraine, taking into account socio-economic cauterization, let us consider such groups K_i $(i = \overline{0,6})$ of citizens (elements) of the society: pensioners (K_0); education, research workers, workers of culture, medical workers (K_1); employees (K_2); workers of small business (K_3); workers of big business (K_4); small business owners (K_5); big business owners (K_6). A priori we note that such a breakdown of elements of Ukrainian society into groups has sufficiently substantiated reasons. Let us denote through n_i and u_i respectively the number of group K_i and average savings (liquidity) of a group representative K_i $(i = \overline{0,6})$. Manufacturers of aggregated public goods are the owners of small and big business, and the consumers of this product are all elements of the society. In regard to the basic functions of economic behavior, we shall include the demand function for

the aggregate product Q_α and output function of this product F_α. The function argument Q_α is a purchasing power $\alpha_i u_i / p_a$ (α_i – share of the group's representative savings i $(i = \overline{0,6})$), which are spent on consumption, p_a – the price of the aggregated product), and an argument of the function F_α – production power $\beta_i u_i / p_a$, $i = \overline{5,6}$ (β_i – share of manufacturer's savings in production). The owners of big business also take part in the processes of export and import. The proposed amount of raw material for export is set by function $F_b = F_b\left(\gamma_6 u_6 / p_b\right)$, where $\left(\gamma_6 u_6 / p_b\right)$ – the production power of this export (γ_6 – the share of savings invested by the group's producers K_6 in the export of the raw material, p_b – the price of exported products). Besides the exporting of raw material, owners of big business also import some products, the volume of which is described by function $S_c = S_c\left(\delta_6 u_6 / p_c\right)$, where δ_6 – the share of savings represented by this group, which is invested in imports, and p_c – the price of imported products. Demand for the exported product will be described by the function $Q_b(t)$, and the supply of imported consumer goods to the national economy by the function $F_c(t)$. Through $W(t)$ we will denote the function of destabilization of domestic consumer market. Questions related to the classes of the introduced functions and their identification are the subject of a separate research, but they do not violate the logic of construction of the model. Let us proceed to the process of its formalization.

In the simplest form, the equation of the dynamics of savings of the above-mentioned first five social groups is recorded (groups $K_i, i = \overline{0,4}$). Their representatives receive a steady income s_i, $i = \overline{0,4}$ (pensioners receive a pension, and others – a salary), which is taxable only for working citizens (tax rate κ_0), and the expenditures are related only to the consumption of aggregate products. The rate of change in their savings u_i, $\left(i = \overline{0,4}\right)$ at any given time depends on the difference between income and expense, i.e., is described by the equations

$$\frac{du_i}{dt} = s_i\left(1 - k_i \kappa_0\right) - p_a Q_a\left(\alpha_i u_i / p_a\right), i = \overline{0,4}, \tag{1}$$

Where $k_0 = 0$, $k_i = 1$ $\left(i = \overline{1,4}\right)$.

As the owners of small business produce products only for the domestic market, their income is made up of the cost of sales demand for these products. Costs include, the expenditures on personal consumption of products, salaries for workers and production needs (λ_5 – share of the value created for these needs) respectively. Let κ_1 and κ_2 – wage tax rates

and added (generated) value, and D_5 – the share of the market of manufactured products for small business. Then the equation of the savings of the owner of small businesses will be

$$\frac{du_5}{dt} = \frac{D_5}{n_5} \sum_{i=0}^{6} n_i p_a Q_a \left(\alpha_i u_i / p_a \right) - p_a Q_a \left(\alpha_5 u_5 / p_a \right) - \frac{n_3}{n_5} \left(1 + \kappa_1 \right) s_3 -$$

$$-\left(\kappa_2 + \lambda_5 \right) p_a F_a \left(\beta_5 u_5 / p_a \right). \tag{2}$$

The difference between income and expenditure also forms the right side of the equation of the time savings of the owner of big business, although the structure of its income and expenditure is not the same as that of the owner of small business. Revenue of the representative of group K_6, except for the cost of sold products at the domestic market, also includes the value of exported raw materials. The components of the expenditure part are expenditures on personal consumption, wages for the workers, production needs for output on the domestic market (λ_6 – the share of the value created for these needs), production needs for production output for export (λ_6^F – export duty), the corresponding requirements for the import of products (λ_6^S – import duty). Consequently, the behavior of a dynamic variable u_6 is formalized by the equation

$$\frac{du_6}{dt} = \frac{D_6}{n_6} \sum_{i=0}^{6} n_i p_a Q_a \left(\alpha_i u_i / p_a \right) + \frac{p_b}{n_6} Q_b \left(t \right) - p_a Q_a \left(\alpha_6 u_6 / p_a \right) -$$

$$-\left(n_4 / n_6 \right) \left(1 + \kappa_1 \right) s_4 - \left(\kappa_2 + \lambda_6 \right) p_a F_a \left(\beta_6 u_6 / p_a \right) -$$

$$-\left[\kappa_2 + \lambda_6 + \lambda_6^F \right] p_b F_b \left(\gamma_6 u_6 / p_b \right) - \left[\kappa_2 + \lambda_6 + \lambda_6^S \right] p_c S_c \left(\delta_6 u_6 / p_c \right), \tag{3}$$

Where D_6 – market share of manufactured products for big business. Note that $D_5 + D_6 = 1$, these particles can be determined as follows:

$$D_5 = \frac{n_5 \beta_5 u_5}{n_5 \beta_5 u_5 + n_6 \left(\beta_6 + \delta_6 \right) u_6}, \qquad D_6 = \frac{n_6 \left(\beta_6 + \delta_6 \right) u_6}{n_5 \beta_5 u_5 + n_6 \left(\beta_6 + \delta_6 \right) u_6}.$$

Prices always depend on the demand and supply of the product. Since at the consumer market the supply is determined by the volume of production and imports, then the price p_a depends not only on the difference between supply and demand, but also is proportional to the difference between the price of the imported goods at the foreign market and the price of

goods at the domestic market (i.e. the difference $\left(\mu p_c - p_a\right)$, where μ – exchange rate), as well as a particle Λ_c of the imported goods in the general supply of goods at the domestic market. From these considerations it follows that the equation of price dynamics p_a has the form

$$\frac{dp_a}{dt} = \theta_a \left[\sum_{i=0}^{6} n_i Q_a \left(\alpha_i u_i / p_a \right) - \sum_{i=5}^{6} n_i F_a \left(\beta_i u_i / p_a \right) - \right.$$

$$\left. - n_6 S_c \left(\delta_6 u_6 / p_c \right) W(t) \right] \left[\left(\mu p_c - p_a \right) \Lambda_c \right], \tag{4}$$

Where θ_a – the coefficient of inertia of the foreign market of consumer goods.

The equation (4) introduced into the equation Λ_c is defined as follows:

$$\Lambda_c = n_6 S_c \left(\delta_6 u_6 / p_c \right) W(t) \left[\sum_{i=5}^{6} n_i F_a \left(\beta_i u_i / p_b \right) + n_6 S_c \left(\delta_6 u_6 / p_c \right) W(t) \right]^{-1}.$$

Changing prices p_b and p_c (in foreign currency), i.e., the prices of exported raw materials and imported consumer goods are also related to the change in the differences between the corresponding demand and supply which is described by the equations

$$\frac{dp_b}{dt} = \theta_b \left[Q_b(t) - n_6 F_b \left(\gamma_6 u_6 / p_b \right) \right], \tag{5}$$

$$\frac{dp_c}{dt} = \theta_c \left[n_6 S_c \left(\delta_6 u_6 / p_c \right) W(t) - F_c(t) \right], \tag{6}$$

Where θ_b and θ_c – the coefficients of inertia of the external raw material market and consumer goods market.

Similarly, the rate of exchange rate fluctuation is modeled, which is proportional to the difference between imports and exports, but in value terms. So,

$$\frac{d\mu}{dt} = \theta_\mu \left[p_b Q_b(t) - p_c n_6 S_c \left(\delta_6 u_6 / p_c \right) W(t) \right], \tag{7}$$

Where θ_μ – the coefficient of inertia of the exchange rate is relative to the change in trade balance.

The system of equations (1)-(7) needs to be supplemented by the initial conditions

$$u_i^0 = u_i(t_0) \ \left(i = \overline{0,6}\right), \ p_k^0 = p_k(t_0) \ (k = a,b,c), \ \mu_0 = \mu(t_0).$$
(8)

In the final result, the ratio (1)-(8) is a dynamic economic model with significant share of exports of raw materials and imports of consumer products. This is exactly the situation in Ukraine in the first decades of the XXI century.

Analysis of the results of experimental studies with the model

Developed for the model (1)-(8) with the help of the Matlab computing system, the software allowed to carry out a number of computational experiments aimed to the research of socio-economic processes that took place in Ukraine in recent decades. With regard to the parameters and functions of the model, they were obtained on the basis of various statistical and expert data, as well as certain theoretical prerequisites and additional researches (Voynarenko, 2017; Toshkov, 2010). We will describe the main qualitative results of the conducted research, which adequately reflect the recent and current economic realities that have been developed in our country.

These realities were complicated for citizens with stable incomes $\left(u_i(t), \ i = \overline{0,4}\right)$. Their savings, starting from the moment of the fall of the economy are rapidly falling, and subsequently remain almost unchanged, although they are different for different groups (Fig. 1).
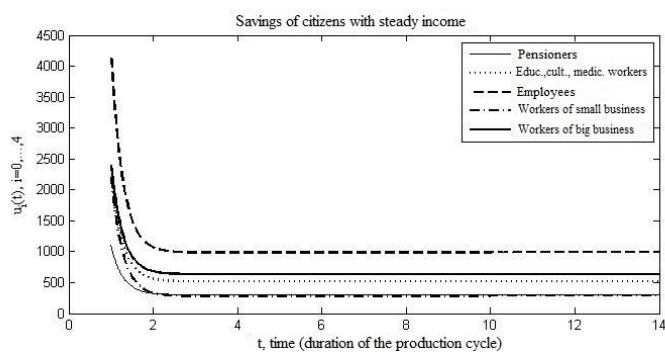

Fig. 1. Savings curves of citizens with steady income $\left(u_i(t), \ i = \overline{0,4}\right)$

The fall in the standard of living of these elements of the society is accompanied by many negative phenomena, such as late payment of salaries, mass emigration, inaccessibility of meeting many social needs, etc.
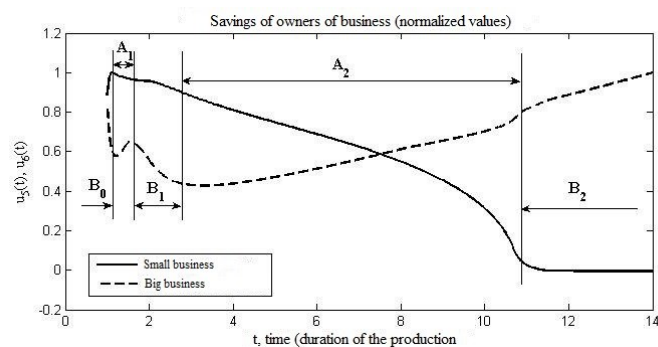
Fig. 2. Charts of normalized values of savings of owners of small and big business $(u_5(t)$ i $u_6(t))$
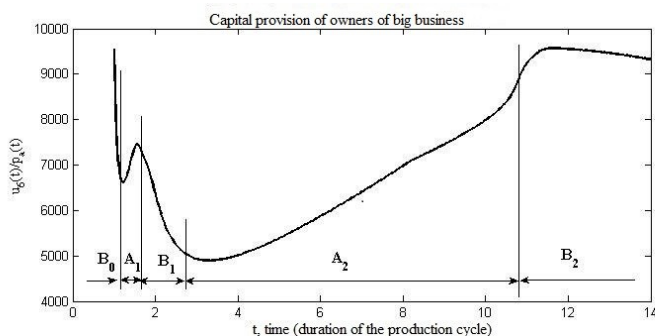

Fig. 3. Chart of capital provision $u_6(t)/p_a(t)$ of owners of big business

Fig. 2 and 3 depict the savings charts of small and big business owners, respectively $(u_5(t), u_6(t))$ and the chart of capital provision $u_6(t)/p_a(t)$ of production of aggregated product by owners of big business. A characteristic feature of these charts is that, besides the general tendency of time changes in these indicators, they also reflect the specifics of economic processes that took place over five intervals of time B_0, A_1, B_1, A_2, B_2. These intervals are peculiar "phases" or periods of transformation of planned state economy into market-driven private economy. These are the transient processes. It is clear that the initial conditions (8) describe the state of the economy at the beginning of these transformations.

Initial period B_0 – is a period of market transformations for producers, the results of which have already manifested in the period A_1. It was then, when the savings $u_5(t)$ of owners of small business continued to decrease, and the savings $u_6(t)$ of owners of big business began to rise. The share of the market of products produced by big business and the share of imports also grow, although the consumption of citizens with stable incomes is decreasing. The period of time B_1 is characterized by the fall of capital of the owners of big business, but the decline in capital provision for small business is slowing down. During the period A_2 all business reduced the production of consumer goods, but the owners of big business increased the import of this product and export of raw materials. This led to a decline $u_5(t)$ and growth

$u_6(t)$. At the same time, the increase in the savings of the representatives of the group K_6 intensified their expenses for participation in public administration.

The last period B_2 simulates a long economic process, when only the savings of the owners of big business rise, and the savings of all other groups K_i $(i = \overline{0,5})$ fall to the living wage. This situation indicates a short-sightedness of the economic policy of the owners of big business and their influence on public administration, as far as capital provision $u_6(t)/p_a(t)$ in the period B_2 begins to decline (Fig. 3). Therefore, even this situation is unprofitable for them, because lack of funds leads to the loss of economic and political power. Besides, during the period B_2 there is an increase in the price p_a of the consumer product (Fig. 4), as well as in prices of exported raw materials and imported consumer products and in the exchange rate $\mu(t)$, that significantly impairs the socio-economic situation of the country, for example, leads to a fall and, thus, extremely low standard of living for pensioners (Fig. 5).
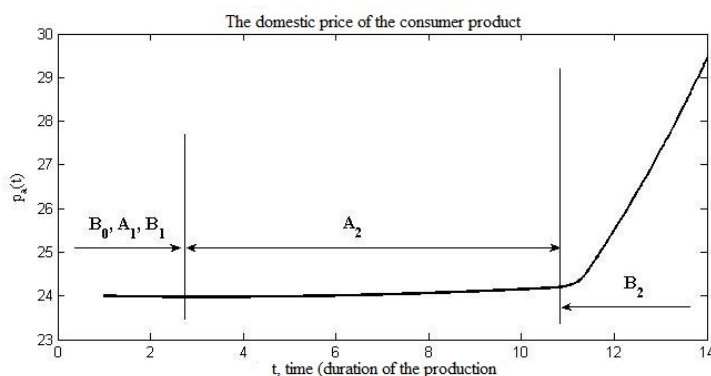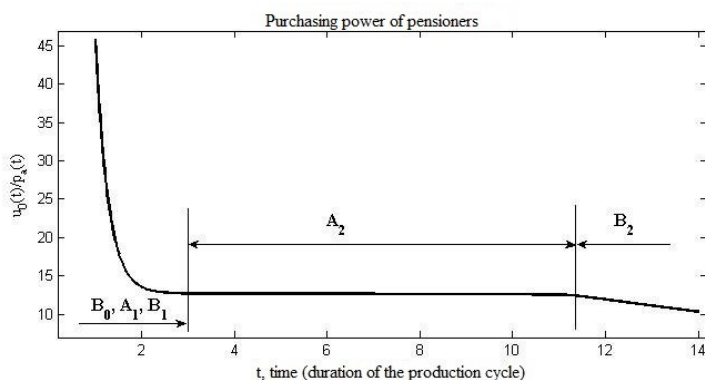

Fig. 4. Chart of consumer price $p_a(t)$

Fig. 5. Chart of purchasing power $u_0(t)/p_a(t)$ of pensioners

It should be noted that the above results of experimental researches with model (1)-(8) usually depend on its parameters. In this regard, the research of the dependence of economic

dynamics on individual parameters of the model is also relevant. Let us describe some of the results of this research.

The influence of inertia of market pricing on the change of prices and savings is analyzed. The experiments with the model show that the reduction of the inertia of the domestic market (rise θ_a) leads to a decline in purchasing power of the citizens with stable incomes and the capital provision of consumer products production by big business. The reduction of inertia formation of foreign exchange (rise θ_μ) leads to the same effect. As for the external market of raw materials, the reduction of its inertia (rise θ_b) is beneficial to the owners of big business engaged in the export of raw materials, since the rate of decline in their power $u_6(t)/p_a(t)$ is reduced. This ability is significantly influenced by the coefficient of inertia θ_c of the external market of consumer goods, the growth of which shifts the graphs of the indicator of power to the left $u_6(t)/p_a(t)$ (Fig. 6). This actually means that a number of economic events in our economy are coming in the past, in particular, by increasing the costs of importers (owners of big business) for participation in the government (the emergence of a minimum of power $u_6(t)/p_a(t)$ in the IV region), reduction of their profitability (reduction of the power chart $u_6(t)/p_a(t)$ from the extreme in the region III), etc.
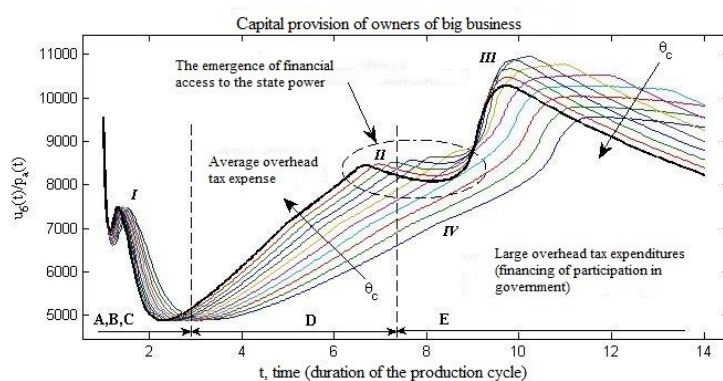

Fig. 6. Charts of the dependence of the capital provision $u_6(t)/p_a(t)$ of the owners of big business on the inertia of pricing in the external market for the supply of consumer goods

These patterns show that the reduction of the characteristic time span of changing the situation of the external market of consumer goods directly affects the intensity of the formation of an existing type of economy in our country. That is, the modern mobility of the external consumer market is an important factor in the emergence of economic dependence of the national economy from foreign producers and importers of consumer products.

The urgent problem of the modern economy of Ukraine is the necessity of diversification of production (increase of assortment of goods of domestic production). In the

developed model, the cost of producing novelties is described by the parameter β_6, i.e., the share of costs of owners of big business in the production of consumer products.

Based on IT calculations established that the increase in the share of production costs β_6 by the owners of big business leads to a faster flow of economic processes (phase changes). The increase in share β_6 is beneficial for owners of big business in the long run (Fig. 7). The increase β_6 leads to a narrowing of the sales of goods produced by small business. Small business completely cease production (Fig. 8), the sector of the economy is occupied by big business. It means that "diversification of production" by "increasing the production costs of the owners of big business" (the creation of new business in the country) has negative social consequences, as the sector of the small business disappears due to a significant difference in capital provision.

The analysis of the reaction of the studied economy (based on the developed model) to the change in consumption Q_a shows that demand growth increases the overall power of small business owners (Fig. 9).
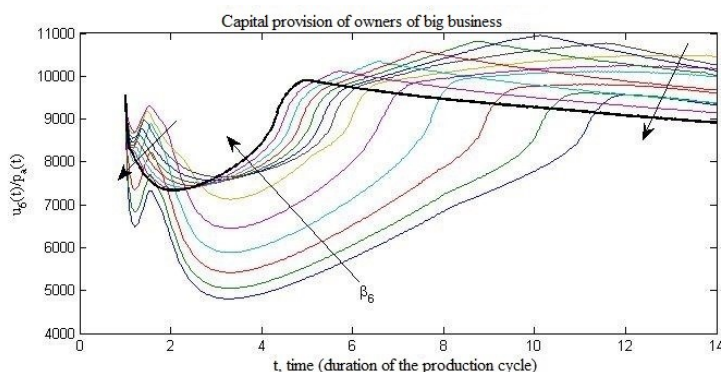

Fig. 7. Charts of dependence of capital provision $u_6(t) / p_a(t)$ of owners of big business on the share of production costs β_6
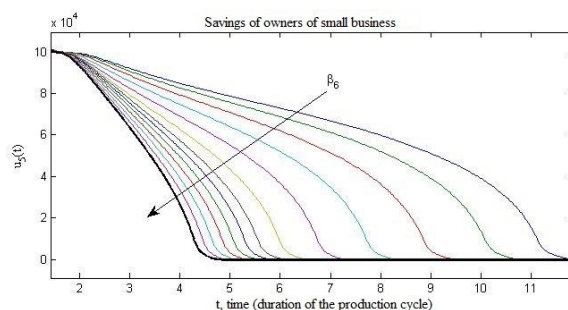

Fig. 8. Charts of dependence of capital provision $u_5(t) / p_a(t)$ of owners of small business on the share of production costs β_6 by owners of big business
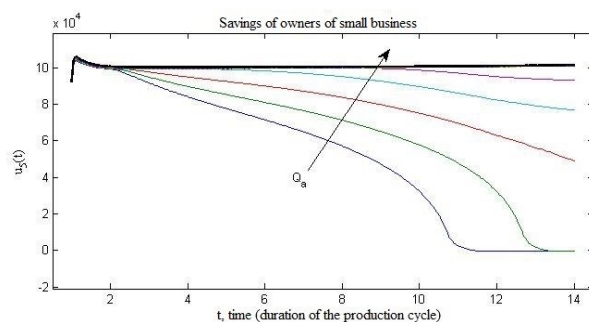
Fig. 9. Charts of dependence of capital provision $u_5(t)/p_a(t)$ of owners of small business on consumption Q_a

The impact of technology productivity, which describes the function F_a is also important for the economy. As a result of computational experiments, it has been established that increase in the productivity of technologies in national sector of production of consumer goods leads to an earlier change in the economic phases (faster flow of economic processes). Change ot the productivity of technologies leads to a short-term strong unilateral change in the savings $u_6(t)$ of the owners of big business and a their long-lasting weak opposite directed change (Fig. 10).

The increase of efficiency of capital (F_a) leads to increase in the savings of the owners big and reduction in the savings of the owners of small business. Consequently, technological improvement in production increases the financial disparity between the owners of big and small business. This discrepancy stems from the fact that operations in a low-performing economy give a relatively higher income to a participant with a higher financial capability. Such an economy acts as a "demon Maxwell".

It is established on the basis of IT calculations, the fact that the increase in demand $Q_b(t)$ for exported raw materials (in foreign markets) improves the financial power of the owners of big business and worsens the financial power of the owners of small business and all groups of citizens with stable incomes (Fig. 11). In this sense, the export of raw materials is profitable only for the owners of big business.
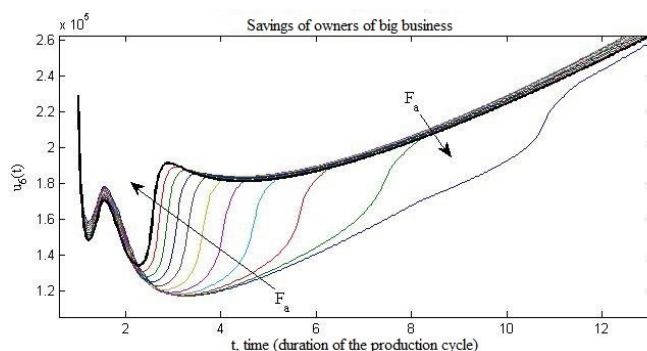

Fig. 10. Charts of dependence of savings $u_6(t)$ of owners of big business on the productivity of
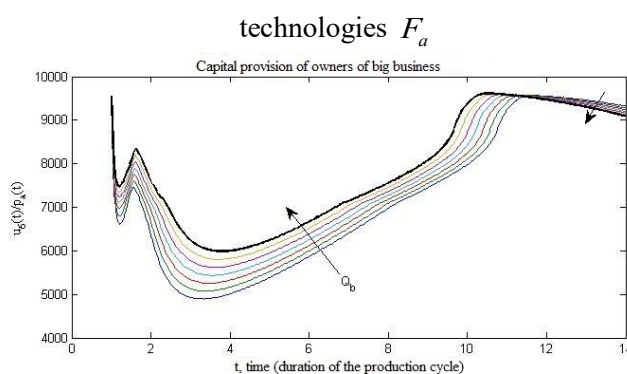
technologies F_a

Fig. 11. Charts of dependence of savings $u_6(t)$ of owners of big business on the demand for raw material $Q_b(t)$ at the foreign market

The increase in foreign supply F_c of consumer goods for import into the national economy also increases the financial power of big business and reduces the financial power of small business. Computational experiments with the simulation of artificial market destabilization by means of the function $W(t)$ confirm the conclusions obtained through qualitative analysis of the solutions of the model.

Taking into account the significant share of the shadow sector in the domestic economy (Buyak, 2007), the impact on economics of the salary s_4 of workers of big business was also research. For example, the increase of wages of workers of big business turned out to an increase in the savings of the owners of small business (Fig. 12) and a decrease in the cost of entrepreneurs for their participation in the government. Consequently, raising of salaries for big business is the "simplest" way not only to increase the financial power of the owners of small business, but also to achieve a single-modal structure of the Ukrainian society and the transition of the economy from low-productive to high-yielding one.
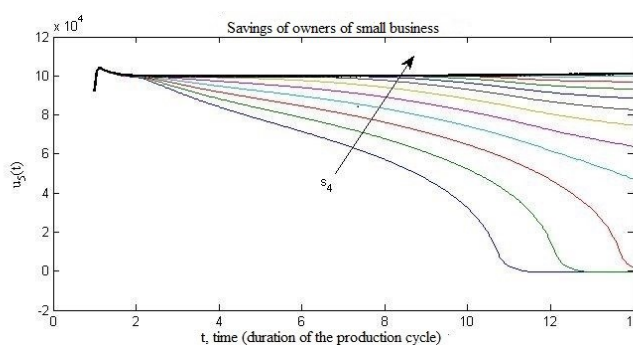

Fig. 12. Charts of dependence of savings $u_5(t)$ of owners of small business on salaries s_4 of workers of big business

Conclusion

The proposed dynamic economic model in this paper is described in the space of economic variables, which include savings (liquid assets) of seven groups of the society, prices for consumer products in the domestic and foreign markets, the price of exported raw materials and the exchange rate. The model is intended for the research of the real economic processes in the mode of computer simulation with it. The experiments carried out with the model with the use of IT technologies allowed to obtain a number of important conclusions that adequately reflect the real events of the modern Ukrainian economy.. It turned out that nowadays owners of big business have a significant influence on the economy, whose activity leads to a decrease in the standard of living of the citizens with stable incomes and the owners of small business. Foreign economic activity of the owners of big business only deepens the differentiation of the society for the poor and the rich.

The prevailing economy is a market liberalized economy with the centralization of political and economic power. The reason for such economy is such negative phenomena as the reduction of volumes of production of consumer goods by small business; reduction of consumption of durable goods, displacement from the domestic market of goods of national production by imported goods; entrepreneurs' financing first of all of their participation in local authorities, then – in the state-owned; increasing the financial power of the owners of big business on the basis of reducing the financial power of the rest of the economy.

The investigated economy is low-yielding, therefore, those measures that increase the efficiency of a high-performing economy (for example, increase the investment in production, increase costs of owners of big business for production needs, increase exports of raw materials and imports of consumer goods, increased demand for exported raw materials, etc.) are opposite directed, which in fact confirms experimental research with the model. From these researches follows that over the past decade, the dynamic state of our country's economy (expressed in models of savings and prices), has changed, passing through several phases. The last phase is relatively long-lasting. During it, there is an intensification of economic (property) disparity between a small group of individuals, formally named in the models "owners of big business", and the rest of the society.

Regulatory and commercial relations that have developed in our country, only increase the socio-economic differentiation of the elements of the society and support the bimodal distribution of the society in terms of income and financial opportunities. The economic system operates in a similar way as the so-called "Maxwell demon", sorting people for the rich and the poor. Measures such as the growth of exports and imports, the intensification of international trade, investment and innovation, etc., in the society with a bimodal socio-economic structure, have the opposite effect, increasing financial resources for capital and centralizing power.

Concluding the presentation of the material of this work, we note that the economy described in it, nevertheless has reserves and chances of transition from the low-productive to the high-performance state, which is the subject of future copyright research.

Conflict of interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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