Modeling and coordinated control for the production and economic system

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Abstract

Problems of simulation and control in production and economic system (PES) under condition of economy's modernization are discussed in the paper. The developed control system considers the coordination of three systems – PES, market and taxation institutional system. We take into account the PES features as dynamism, large number of parameters, nonlinearity, nonstationarity, strong interconnectivity and hierarchical structure. The aim of the developed models and coordinated mechanisms is to improve the decisions making effectiveness at the expense of a coherent management in PES.

Keywords: production and economic systems; modeling; coordinated control; coordination of interests; multiple criteria for decision making

1. Introduction

To improve the economy productivity and to create the sustainable innovation development system for enterprises of different industries, organizational and legal forms, sizes and spatial location it is necessary to develop mechanisms of multi-level strategic planning and management. The control system, based on these mechanisms should include strategic planning at different level – the level of enterprise, the level of market agents and the level of state. At the enterprise level the strategic planning system must be unified in functional and management verticals. At the market agent level the development and implementation of strategic plans is to take into account the interests of all enterprise. At the state level, fiscal policy should be formed to be the most active component of economic and industrial policy, focused on the development of the capacity of enterprises as productive and economic system (PES) and its modernization.

Therefore the problem of modeling and controlling tools creating for the PES operation under a systematic modernization of the economy, taking into account the interests of agents matching the most PES, market and institutional environments is of great importance. The solution of this problem and developed application decision will increase the efficiency of controlling processes in PES.

The analysis of the investigations in the field of modeling and control in different organizational systems [1-8] is showed the following. Problems related to the economic-mathematical modeling and control of the processes of harmonization the economic interests of participants in production and economic, in market and fiscal processes are not solved. Previous studies do not deal with dynamic pricing for enterprises products in a competitive market, changing consumer preferences and behavioral strategies of competitors.

2. PES as a controlled object

Industrial and economic system is a complex organizational system combining production, sale and the resources reproduction. It is characterized by dynamism, a number of parameters, strong interconnectedness of parameters, hierarchical structure, the presence of the inverse of the material and information communications, nonlinearity and nonstationarity. The scheme of interaction the PES with macroeconomic systems – state, society is shown in Fig. 1.

State regulate the economy and the PES as a part of the economy, provide security, unity and territorial integrity of the national economy, get the possibility of economic development. The activity of enterprises is carried out under a number of restrictions: technological constraints (production function), financial constraints (the cost of production factors), demand (market size), competitor activity, government regulation, taxes and subsidies, ethical rules and norms (social norms of business), time.

Based on the above, the problem field can be represented as a set of interrelated issues. These questions arise to the process of interaction between the PES as the main system of the economy, producing products to the market as the sphere of activity of agents that influence the economic decisions of PES, as well as to the institutional environment of the state, which determines the rules of economic activity of the PES and a fiscal adjustment.

The following most important key issues can be identified as:

a) ensuring the development of PES through tax incentives;
b) sustainable functioning of the PES through the balancing of resources and results of operations;
c) coordination of economic interests of PES;
d) increasing the management efficiency through the PES agreed with external agents behavior in industrial market.

There are a number of contradictions accompanying production and economic activity: PES - tax system, PES - competitors, PES - consumers. These contradictions include the following.

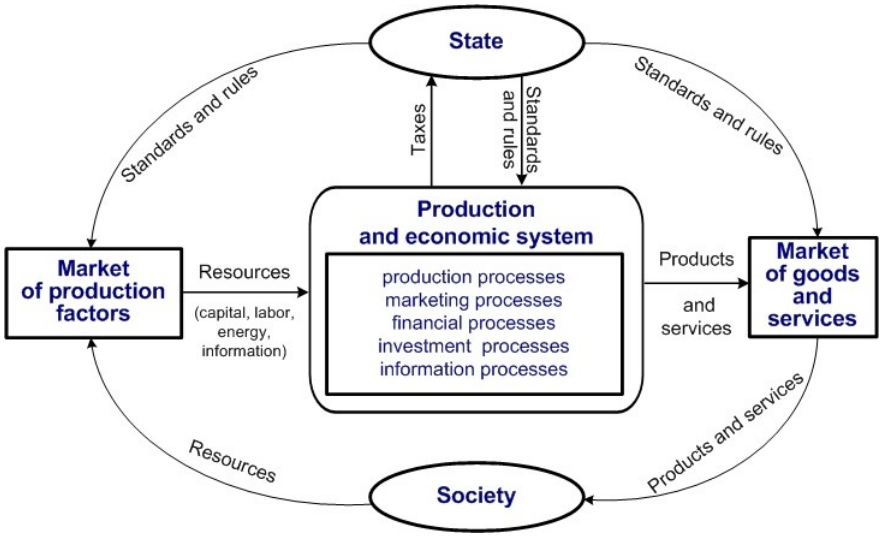

Fig. 1. Interaction of PES with macroeconomic systems.

1. The financial and economic stability of PES and its the effectiveness depend on reducing tax payments and the stability of the economy connected with the growth of tax revenues into the budget. Smoothing of this contradiction of interests can be can be achieved by the harmonizing the tax burden on PES and the level of tax rates that provide both the PES development and required budget revenues.

2. When selling the product on the market PES aim to maximize its revenues at the expense of highest possible price in completive market. Consumers make there choice of those products which has minimum price with equal quality. Resolution of this contradiction is possible due to adaptive pricing that ensures the coordination of PES utility functions, competitors utility functions and consumers preferences.

3. When implementing strategic goals aimed at long-term growth and development PES should monitor solvency and liquidity in order to avoid risks associated with a decrease in the level of sustainability and solvency in the short term. This requires a set of measures aimed at managing financial resources and cash flows and providing coordinated management at the strategic and operational levels of the PES system management.

4. Management of the PES stability can be realized by balancing: resource flows, output volumes and products price by the criteria of profitability and profit.

These contradictions are formed with the synergetic interaction of economic systems - the enterprise as a PES, the market system and the tax system and can be resolved through the development of models, methods and mechanisms for managing the interaction of these systems on a single methodological platform. In order to solve the problem of reconciling the multidirectional interests of subsystems - PES, market and tax systems, it is necessary to create a decision support toolkit under uncertainty to ensure a PES and economy efficiency increasing. The problem of PES management features are:

1) complexity of control object;
2) synergistic impact of factors and uncertainty on the process of PES functioning and development;
3) necessity of PES management system efficiency increasing to ensure PES sustainability;
4) necessity to harmonize the multidirectional interests of interacting systems to ensure economic growth.

Therefore, the problem of conflicting interests harmonizing of PES, market and tax systems at different management levels, developing tools for supporting decision-making under conditions of uncertainty is urgent. The management system should include management at the PES level, at market agents level and at the state level.

3. Conceptual basics for the PES modeling and control

Models for PES process control based on complex interactions of diverse subsystems, ensuring consistency of economic interests of participants of the economic, financial and market processes. The control system structure is defined in the form of three blocks: 1 – block for providing an effective enterprise resource management system, aimed at harmonizing the strategic and operational levels of management (project management, processes); 2 – block for adaptation of market management mechanism that supports the interests of consistency of producers and consumers (control pricing processes); 2 – block for tax burden and tax rates regulation as an instrument of fiscal policy, aimed at improving economic growth in general (management of the institutional environment). Solution of these problems is based on simulation of a system having a hierarchical structure which includes the components listed below.

a) simulation of the tax burden and tax rates, taking into account conflicting interests of industrial and economic systems (tax subjects) and the economy as a tool of fiscal policy, aimed to the development of the PES;
b) simulation of market interactions of producers and consumers. This section is important because it leads to the formation of market prices, which are among the most important characteristics of the PES effectiveness;

c) simulation of resource component for production and economic system. At this level, it is considered the conversion of resources into results and the aim is to ensure the most efficient allocation of resources for production and to ensure the effective development of the PES.

The coordinated control mechanism for the PES consists of inter-related technologies: the balanced efficiency; the financial planning; the prices control; the technology of synthesis of optimal tax rates. First two technologies are united in subsystem for the PES resources control. Functional diagram of coordinated control mechanism for the PES is shown in Fig. 2.

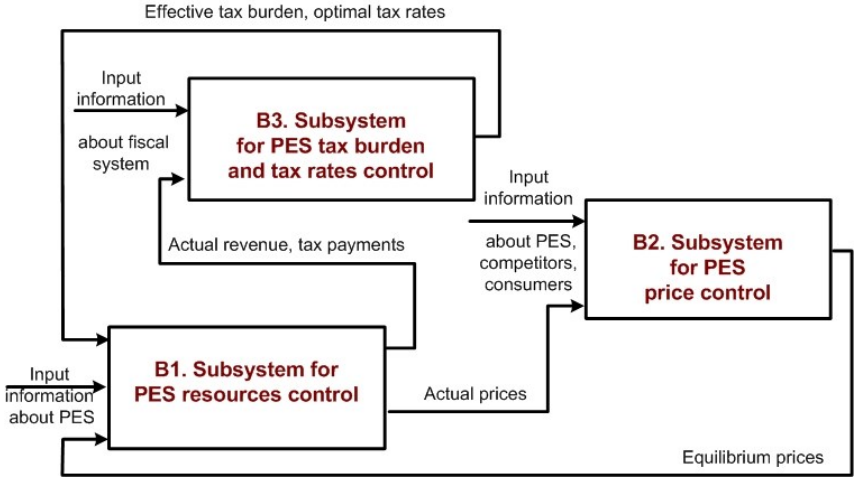

Fig. 2. Functional model for PES coordinated control mechanism.

The hierarchical simulation system is constructed as follows. First level is modeling of optimal tax system [9], includes the model for determining the effective tax burden and the model for determining the optimal level of tax rates on taxes and tax homogeneous groups of subjects [10, 13]. Simulation results at this level area are allowed tax burden in groups of similar taxation objects and the optimal tax rates that satisfy the interests of the taxation objects and the economy as a whole.

The second simulation level is the dynamic model of market pricing, designed for the PES control in conditions of nonstationarity of environment parameters and dependence spheres of production and consumption on the basis of the adaptive pricing mechanism. Prices level formation and changing are coordinated both with the strategic objectives of the manufacturers and the changing preferences of consumers [11, 12]. The result of the modeling of market processes are Nash equilibrium prices for manufactured products that achieve the maximum efficiency for PES.

The third simulation level based on production and economic system control models, designed for the optimal combinations of production resources within the constraints generated by the first and second levels of modeling [13, 14]. Modeling results are the resources costs, production quantity and prices for production and economic system.

4. Models for PES control

The model of economic efficiency of production is formed as the ratio of profit and production costs:

$$\alpha = \frac{\Pi}{C}, \tag{1}$$

where the profit is

$$\Pi = pq - \left(C_{\mathrm{f}} + q \cdot C_{\mathrm{v}}\right). \tag{2}$$

Total production cost is defined as the sum of variable and fixed costs

$$C = C_{\mathrm{f}} + q \cdot C_{\mathrm{v}}, \tag{3}$$

where α is the profitability of goods production in q quantity, Π is the gross profit generated on the sale of goods in q quantity and p price, C is the total cost, including a constant part C_{f} and a variable part qC_v. The profit tax payable to the budget is defined as

$$T_{\mathrm{PT}} = t_{\mathrm{PT}} \cdot \Pi, \tag{4}$$

where T_{PT} is the profit tax, t_{PT} is the profit tax rate.

The basis of tax burden simulation is the Laffer assumption about the nonlinear connection of output X and the level of tax burden θ. For each group of similar taxation objects we design the dependences as the follow

$$\theta = T / X, \tag{5}$$

where θ is the tax burden, T are the tax revenues.

We assume that the production also has non-linear relation with the tax burden. The production function is approximated by a quadratic polynomial:

$$X(\theta) = a\theta^2 + b\theta \tag{6}$$

and the tax function $T(\theta)$ has the form:

$$T(\theta) = a\theta^3 + b\theta^2, \tag{7}$$

where *a* and *b* are function parameters. Identification of production function $X(\theta)$ and tax function $T(\theta)$ allow to find the first and second Laffer points in which the production and tax functions has their maximum respectively.

Harmonization of the operational financial planning system and the strategic financial planning system is provided due to coordination of special indicators of operational and strategic control levels. At the operational enterprise level it is ensured the products competitiveness, the overall status of PES and its financial and operating efficiency, at the strategic control level it is conducted the enterprise investment attractiveness, the growth of its value in the long term. Interconnection of these indicators is based on a multifactor model

$$ROE = \frac{\Pi - T_{PT}}{E} = \frac{\Pi}{A} \cdot \frac{A}{E} \cdot \frac{NI}{EBIT} = ROA \cdot LR \cdot B, \quad (8)$$

where *ROE* is the return on equity; *NI* is the net income; *E* is the equity capital; *EBIT* are the earnings before interest on loans and income tax; A is assets; *ROA* is return on assets; *LR* is the coefficient that determines the effect of financial leverage; *B* is the coefficient reflecting the decrease in profitability of the enterprise in the payment of interest on the capital employed and tax deductions.

The model of competitive interaction of the enterprises (in the case of a duopoly) is represented as mapping:

$$\begin{cases} p_1(t+1) = p_1(t) + k_1 \dfrac{\left(-p_1^2(t)p_2(t) + 2c_1p_1(t)p_2(t) + c_1p_2^2(t)\right)}{\left(p_1^2(t) + p_1(t)p_2(t)\right)^2}, \\ p_2(t+1) = p_2(t) + k_2 \dfrac{\left(-p_1(t)p_2^2(t) + 2c_2p_1(t)p_2(t) + c_2p_1^2(t)\right)}{\left(p_2^2(t) + p_1(t)p_2(t)\right)^2}. \end{cases} \quad (9)$$

where $p_1(t), p_2(t)$ are the prices of products of the first and second firms, taken at discrete intervals of time *t*; second terms in both equations show how the change in prices in period *t*, and how this change will affect the price in the next period. Parameters k_1 and k_2 represents the increase in prices due to changes in the pricing policy. Variables c_1 and c_2 represents production cost of the first and second firms respectively.

5. Numerical results

We consider the computational experiment implemented the designed harmonized mechanism for the tax burden and tax rates. Modeling is based on the statistical data for several years about taxable bases for individual taxes, tax revenue for five classes of PES - large enterprises, providing about 50 % of tax revenue into the region budget. Further we give modeling results for the aggregate tax burden and the tax becoming the first group of taxpayers. The first taxpayers can be described as the largest taxpayer, which has the following structure of taxable bases: the share of value-added tax is 0.576; profit taxes - 0,125; the unified social tax - 0,098; property tax - 0.08; other taxes - 0,121.

Production and tax functions, as well as their extremes are:

$$X_1(\theta) = -141.5 \cdot 10^7 \theta^2 + 400.1 \cdot 10^6 \theta, T_1(\theta) = -141.5 \cdot 10^7 \theta^3 + 400.1 \cdot 10^6 \theta^2, \quad \theta^* = 0.13, \theta^{**} = 0.19. \quad (10)$$

Analysis of the actual total tax burden for the first group of taxation objects shows that in periods *t* and *t*-1, its value is more than two points Laffer θ* and θ** and is equal to 0.23 and 0.25 respectively. The insensitive area for the tax burden is from 0 to 0.09 (θ_h), Fig. 3.

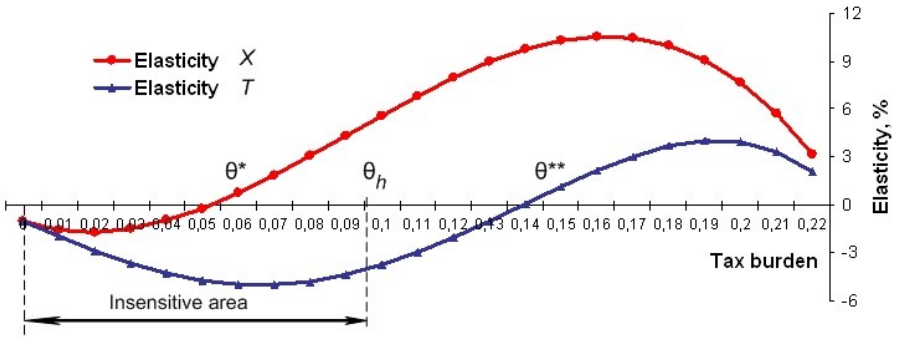

Fig. 3. Elasticity function for the production and tax revenue.

Detailed analysis of the production and tax functions for the first group of enterprises showed that the current tax burden is such that there is in the third zone. This corresponds to a situation in which the tax burden is the right of both the Laffer points. This means that fiscal policy stimulates the fall of the production function, while dissatisfaction fiscal interests. Therefore it is a great necessarily for reduce the overall tax burden, which will increase the value of production and tax functions simultaneously, table 1.

Consider the several cases to change (decrease) in the overall tax burden for first group objects of the. The most significant increase in the production function is achieved at the tax burden level of 13-14 %, but further reduction in the tax rate will not give further effect in the tax revenues growth. Elasticity's analysis of the production and tax functions showed that the area of insensitivity can be determined as [0; 0.09], since this segment is the growth of the tax burden leads to a greater reduction in tax

revenue than that achieved for a given load in output growth. Therefore the recommended decision is to reduce the overall tax burden up to 14 % or 9 %.

Table 1. Growth rates for production and tax functions.

Tax burden changing $\Delta\theta$	New tax burden θ	Growth rate for function X	Growth rate for function T
-	0,23	-	-
0,01	0,22	0,138	0,089
0,02	0,21	0,260	0,150
0,03	0,2	0,365	0,187
0,04	0,19	0,454	0,201
0,05	0,18	0,526	0,194
0,06	0,17	0,581	0,169
0,07	0,16	0,620	0,127
0,08	0,15	0,643	0,071
0,09	0,14	0,649	0,004
0,1	0,13	0,639	-0,074
0,11	0,12	0,612	-0,159
0,12	0,11	0,568	-0,250
0,13	0,1	0,508	-0,344
0,14	0,09	0,432	-0,440
0,15	0,08	0,339	-0,534
0,16	0,07	0,229	-0,626
0,17	0,06	0,103	-0,712
0,18	0,05	-0,040	-0,791
0,19	0,04	-0,199	-0,861
0,2	0,03	-0,374	-0,918
0,21	0,02	-0,566	-0,962
0,22	0,01	-0,775	-0,990
0,23	0	-1,000	-1,000

Changing the overall tax burden is possible by changing tax rates. Moreover, the conceptual analysis of the types of taxes remains within the Laffer theory that maintains the unity of methodological research. Therefore, for qualitative and quantitative analysis of the need to build on each group of objects depending on tax bases of each taxes: value added, income, profit, property. For the first taxpayers group tax production functions for each type of tax as well as the extreme points of these functions, and the actual tax burden value are as follows (for value-added tax, for profit tax, for income tax, for property tax correspondingly):

$$X_{11}(\theta) = -107.3\cdot 10^6\theta^2 + 548.5\cdot 10^5\theta, T_{11}(\theta) = -107.3\cdot 10^6\theta^3 + 548.5\cdot 10^5\theta^2,\ \theta^* = 0.28; \theta^{**} = 0.35, \theta = 0.37,$$
$$X_{12}(\theta) = -273.2\cdot 10^8\theta^2 + 715.8\cdot 10^7\theta,\ T_{12}(\theta) = -273.2\cdot 10^8\theta^3 + 715.8\cdot 10^7\theta^2,\ \theta^* = 0.23; \theta^{**} = 0.34, \theta = 0.15$$
$$X_{13}(\theta) = -368.7\cdot 10^6\theta^2 + 479.3\cdot 10^5\theta,\ T_{13}(\theta) = -368.7\cdot 10^6\theta^3 + 479.3\cdot 10^5\theta^2,\ \theta^* = 0.07; \theta^{**} = 0.09, \theta = 0.08,$$
$$X_{14}(\theta) = -273.2\cdot 10^8\theta^2 + 715.8\cdot 10^6\theta,\ T_{14}(\theta) = -273.2\cdot 10^8\theta^3 + 715.8\cdot 10^6\theta^2,\ \theta^* = 0.009; \theta^{**} = 0.016, \theta = 0.02. \quad (11)$$

Many tax rates combinations that implements the single changing in total tax burden can be represented in the form of the matrix. For the analyzed companies there have been determined the particular solution, and presented in the form of a matrix A. The elements of this matrix reflects the need to transform the specific tax rates in the form of an increase / decrease in implementing the first option - reducing the overall tax burden in 1% lead to the increase in the production function in 14 % and the growth of the tax function in 9 %:

$$A = \begin{Vmatrix} -0.02 & 0.05 & -0.01 & -0.01 & 0 \\ 0.07 & 0.11 & 0.05 & 0.23 & 0 \\ 0.02 & 0.33 & -0.08 & -0.53 & 0 \end{Vmatrix}. \quad (12)$$

It should be noted that the proposed change in tax rates implements only one of the possible options for fiscal policy, which allows to increase the efficiency of the fiscal system. Modeling of competitive tax system and finding the optimal tax rates on different PES groups is presented in [9].

6. Conclusion

The proposed approach for PES modeling and control is differ from similar ones in that takes into account its properties, complex nonlinear relationships between economic agents of internal and external environment. This allow to simulate the processes of PES functioning in conjunction with the economic agents, agreeing in control their conflicting goals and criteria.

The conceptual model for the PES control defines a single system-methodological position for control structure in the form of three blocks: creation the effective PES control system that ensures the coordination of strategic and operational management processes in the PES; formation the effective pricing system for the PES as a market mechanism for strategic cooperation with competitors and consumers; formation the tax burden and tax rates as an instrument of fiscal policy, aimed to stimulating the PES development and economic growth. Conceptual model is the basis of the methodology and aims to improve the decisions making effectiveness at the expense of a coherent decision-making in PES control system.

The proposed scheme of PES control system unites disparate economic and mathematical methods and models, reflects the heterogeneous properties of PES and provides a synthesis of efficient control algorithms. Developed decision support tools for the PES control in the form of control mechanisms, methods and models has been implemented as an integrated software package.

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