Advances in Social Science, Education and Humanities Research, Volume 489
Proceedings of the International Conference Digital Age: Traditions, Modernity and Innovations (ICDATMI 2020)

Model Analysis of the Russian Electric Power Industry in the Context of Digitalization

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Abstract—**Reforms in the Russian electricity power sector are entering the final stages. However, there are also unsatisfactory results of their implementation along with the positive ones such as the use of the mechanisms of the so-called " merit order pricing" (MOP) and "capacity adhesion contract" (CAC). These mechanisms are aimed at maintaining the operations of existing and construction of new non-competitive stations by increasing the supplied electricity price from its equilibrium market value. However, the use of these mechanisms creates a serious problem for the Russian economic development. If one considers these mechanisms in the power as a whole, then they contribute to the energy efficiency within the sector through supplied electricity price increase, and, at the same time, they significantly limit the opportunities for economic growth for other industries. This is due to the fact that the supplied electricity price hike entails the need to increase prices for their output. The increase in the supplied electricity price of even by 10% leads to the slowdown in economy. The article analyzes the marginal system of quasi-market pricing in the Russian power industry. A basic model of the activity of economic market participants in the context of digitalization has been developed on the basis of the previously constructed dynamic probabilistic model of economic systems. Its application has proven the negative impact of merit order pricing on the economic system. A better way of handling this and maintaining ineffective economic entities in the power industry, various methods of direct budgetary support while maintaining the market price for supplied electricity should be used instead of using quasi-market merit order pricing.**

Keywords— ***electric power industry, digitalization, base model, dynamic probabilistic model, merit order pricing***

I. INTRODUCTION

The power industry is an important focus for the study of economic systems. In the context of "market-oriented" reforms, quasi-market mechanisms have been introduced for preserving existing and building new non-competitive capacities in this sector, using the mechanisms of "merit order pricing" and "capacity adhesion contract" [1, 2].

One of the main provisions of reforming the electric power industry in the Russian economy consisted of the attractive conditions creation for private investment flows [3-5]. These flows will promote a competitive market formation, contribute the stabilization of this market and reduce electricity prices in the short term [6]. This claim however was initially untenable as there exists a significant gap between the cost of repair existing and construction of new capacities and the value of the current capitalization of electric power companies. This gap is associated with the low solvency of the main electricity consumers – the population of Russia and enterprises of certain industries. As a result of the reforms carried out, the private investment flows in the electrical industry came short than the expected one. This resulted in an annual increase in electricity prices.

In this regard, the purpose of this study is to develop proposals and simulate conditions under which the use of the quasi-market merit order pricing mechanism in the electric power industry will lose its effectiveness. Achievement of the above objectives is expected to result in economic growth in most sectors, and hence of the entire Russian economy.

II. METHODS

Within the framework of classical economic theories, it is quite difficult to analyze the impact of merit order pricing on the country's economy. Therefore, the digital modeling method was used to prove the detrimental effect of the quasi-market merit order pricing mechanism in the electric power industry on the country's economic system [7].

In practice, the relevance of problem-setting and problem-solving is associated with the Russian economy digitalization [8, 9]. This makes it possible to form any types of models based on Leontief matrices, in particular, specific two-product models such as "electric power industry to all other industries" [10]. The feasibility and efficiency of using digital information requires a theoretical and model study of the problem for this industry [11]. Separate problem-solving approaches will be disclosed in this article.

This article shows that the previously developed dynamic probabilistic model of economic systems was used to analyze the negative impact of merit order pricing in the context of digitalization [12-16]. Its application makes it possible to solve development practitioners of the most important multi-agent industries in their interaction with the economic system.

III. BEFORE STYLING BRIEF DESCRIPTION OF THE MODEL

The dynamic probabilistic model of economic systems proposed by Grachev I.D. [12-14] can be briefly described as follows:

1. The development of the economic system will be considered as an equivalent to a monotonically growing capacity accumulation (resources, information, technologies, etc.) on average measured in monetary terms.

2. The actions of the market economic agents will be considered limitedly irrational. This presupposes an assessment of the means and a limitation of the variance of the deviations of such actions from the classically rational ones.

3. The market economic agents are diverse, in particular, they are differently wrong.

4. The market economic agents are non-additive and, therefore, the market is not the sum of agents' actions, but their statistical universe. This aggregate offers cooperative properties, including an assessment of the market value.

5. The probabilistic model was chosen as the simplest one taking into account the experimentally verified significant residuals of economic measurements and estimates, from indistinguishable mathematical descriptions of irrationality [3, 17].

6. In the "money-goods-money" scheme in goods circulation, the resource component of the products involved in the exchange does not matter.

The capital α_j is used as characteristic of each economic agent and ξ_j as the error of its use in exchange operations. The collective estimate of their market values <c> is used as characteristic of the statistical universe of economic agents that form the market. It is assumed that <c> is the weighted average of all exchange transactions and, therefore, corresponds to the cumulative error in the measurement of market values. Then the simplest dynamic probabilistic model can be represented as follows [12, 15]:

$$\bar{A}_{i+1} = \bar{A}_i - \mathrm{diag}(\bar{\xi}_i) \cdot \bar{A}_i + \frac{\bar{A}_i^T \cdot \bar{\xi}_i}{\bar{A}_i^T \cdot \bar{I}} \cdot \bar{A}_i \quad (1)$$

i – cycle number;

$\bar{A}$ – the capital distribution vector over j-agents on the i-cycle;

$\bar{I}$ – unit vector;

$\bar{\xi}_i$ – normalized vector of the cost price by j-agents;

$\frac{(\bar{A}_i^T \cdot \bar{\xi}_i)}{(\bar{A}_i^T \cdot \bar{I})} = <\bar{\xi}>_A$ – «capital» averaging, i.e. transactions weighted average by capital.

$$[\bar{A}]_j = a_j \quad (2)$$

$$[\bar{\xi}]_j = \xi_j \quad (3)$$

The model (1) describes a closed market with the total capital conservation law. The consequences of the model (1) are: 1) the condition for the development of the economic system, i.e. the growth in i accuracy of measuring market values; 2) the stabilizing role of government regulation in the case of an excessive scatter of answer on the formula (1) with large values of errors in the use of capital in exchange transactions ξ_j.

The simplest version of the open market can be represented through the introduction of an additional economic agent and its certain resources (capital, labor, information, technology, etc.) [18]. In this case, the formula (1) is becoming as follows formulas (4) - (5):

$$\bar{A}_{i+1} = \bar{A}_i - \mathrm{diag}(\bar{\xi}_i) \cdot \bar{A}_i + \frac{\bar{A}_i^T \cdot \xi_i + \bar{P}_i \cdot \mu}{\bar{A}_i^t \cdot \bar{I} + P_i} \cdot \bar{A}_i \quad (4)$$

$$\bar{P}_{i+1} = \bar{P}_i - \bar{P}_i \cdot \mu + \frac{\bar{A}_i^T \cdot \xi_i + \bar{P}_i \cdot \mu}{\bar{A}_i^T \cdot \xi + \bar{P}_i} \cdot P_i \quad (5)$$

$\bar{P}_i$ – resources available to market agents;

μ – parameter characterizing the ratio of resource availability to the efficiency of economic agents' activity

According to [12-15], the condition for the economic system's development, in terms of the capacity accumulation, is presented as follows:

$$< \mu > < \xi > = \frac{\bar{A}_i^T \bar{\xi}_i}{\bar{A}_i^T \bar{I}} \quad (6)$$

Consequently, the formulas (4) - (6) will be minimally sufficient ones to explain the classic market crises and their impact on the slowdown in the economic system's development because the weighted average by prices <c> is a random variable. At the same time, it is assumed that investments are not attracted due to the limited availability of resources <P>.

Put the case that the resources availability is not limited for a qualitative analysis of the impact on the economic system's development of various pricing mechanisms. This condition is represented by the formula (7):

$$P_i \gg \overline{A}_i^T \times \overline{I} = Q_i \tag{7}$$

Q_i – total capital of the economic system.

The formulas (4)-(7) can be worked out to (8):

$$\overline{A}_{i+1} \cong \overline{A}_i - \mathrm{diag}(\overline{\xi}_i) \times \overline{A}_i + \mu \overline{A}_i \tag{8}$$

It should be noted that there are

$$< \overline{\xi}_{i+1} > - < \xi_i > \ll \mu - < \xi > \tag{9}$$

and uncorrelated residuals

$$< (\overline{\xi}_K \overline{\xi}_i^T) >= \mathrm{diag}(\overline{\xi}^2) \tag{10}$$

$\overline{\xi}^2$ – variance matrix,

so, the formula (8) takes approximate answer (11):

$$Q_j(i) = Q_j(i) \cdot \exp((\mu - < \xi_i >) i) \tag{11}$$

This answer (11) for developed quasi-stationary states describes on average the exponential dynamics of economic growth [5, 7, 9, 19-21].

In the formulas (4) - (11) for all economic agents, the market sets one value of the market value. And the deviation from its various assessments of actions and inactions equally affects the change in the capital of each agent [22-28]. In addition, the formulas (4) - (11) made it possible to address a number of economic challenges and obtain certain results in the development of a dynamic probabilistic model of economic systems [6, 7, 9, 21].

IV. RESULTS

One of the key findings was the analysis of the merit order pricing model. To this end, all economic agents should be divided into power generators ($\overline{A}$) and power consumers ($\overline{B}$). Then the formula (8) is modified as follows:

$$\overline{A}_{i+1} = \overline{A}_i \text{-} \mathrm{diag}(\overline{\xi}_a) \cdot \overline{A}_i + \mu \cdot \overline{A}_i \tag{12}$$

$$\overline{B}_{i+1} = \overline{B}_i \text{-} \mathrm{diag}(\overline{\xi}_b) \cdot \overline{A}_i + \mu \overline{B}_i \tag{13}$$

On the basis of an assumption that the weighted average pricing is most consistent with the classical understanding of the market value, then all the above formulas are remained. However, if the actions assessment of some of the agents, who are power generators, turns out to be below average, then they will be forced to reduce their capital and become bankrupt [29-31].

The marginal system for the formation of quasi-market values, in essence, presupposes a shift in the electricity prices for all agents by $\triangle$ c, which guarantees the last producer-agent m a non-negative value of the change in his capital at the i step.

$$\triangle a_m = a_{m(i+1)} \text{-} a_{m(i)} \geq 0 \tag{14}$$

Then the formula (12) is systematically added the capital for a-agents as follows (15):

$$\overline{A}_{i+1} = \overline{A}_i \text{-} \mathrm{diag}(\overline{\xi}_a) \overline{A}_i + \mu \overline{A}_i + \triangle a \overline{A}_i \tag{15}$$

For b-agents who are the power purchaser, this operation will entail a systematic shift in their capital value to the negative side as follows (the formula 16):

$$\overline{B}_{i+1} = \overline{B}_i \text{-} \mathrm{diag}(\overline{\xi}_b) \overline{B}_i + \mu \overline{B}_i \text{-} \triangle c \cdot \overline{B}_i \tag{16}$$

The merit order pricing in the formulas (15) - (16) provides a change in the total capital of the economic system as follows (17):

$$\begin{aligned} Q_{i+1} Q_i &= \overline{A}_i^T \overline{I} \, \mu \overline{A}_i^T \overline{I} \left(\overline{A}_i^T \overline{\xi}_a \right) + \square c \overline{A}_i^T \overline{I} + \\ &+ \overline{B}_i^T \overline{I} + \mu \overline{B}_i^T \overline{I} \left(\overline{B}_i \overline{\xi}_b \right) \square c \left(\overline{B}_i^T \overline{I} \right) = \\ &= Q_i + \mu Q_i \left(\overline{A}_i^T \overline{\xi}_b \right) + \square c \left(\overline{B}_i^T I \overline{A}_i^T I \right) \end{aligned} \tag{17}$$

After that, the point of decrease in the rate of the economic system's development ($\triangle Q_i < 0$) will meet to the following condition:

$$\mu - < \xi > - \triangle c \times \frac{\overline{B}_i^T \cdot \overline{I} \text{-} \overline{A}_i^T \cdot \overline{I}}{Q_i} \geq 0 \tag{18}$$

Taking into account the results of the above analysis, the $\mu - < \xi >$ value can be approximately equated to the rate of annual economic growth (0.03-0.05) and the capitalization of all economic agents in the electric power industry should be taken within 0.03-0.1 of the total capital of the economic system. Then the upper bound can be calculated from the formula (18):

$$0.05 \text{-} \triangle c \times 0.8 \geq 0 \tag{19}$$

And from this it can be got a rough estimate of the permissible relative to the average bias in electricity prices in the amount of:

$$\triangle c \cong 0.06 \tag{20}$$

With the existing scatter of the economic agents' activity efficiency, the ratio of the standard deviation to the average value of income, the formula (19) is practically impracticable. It means that the further use of the merit order pricing system in the power industry is guaranteed to entail a slowdown in the development of the entire economic system.

V. DISCUSSION

It is from this statement that the alternative options for providing support to ineffective economic agents should be discussed. The simplest of the alternative ones should take a detailed look at the option of compensation for losses at the expense of the turnover tax (γ) for all closing economic agents, which guarantees them bankruptcy protection. To this end, the formulas (15) - (16) are transformed into the formulas (21) - (22):

$$\overline{A}_{i+1} = \overline{A}_i\text{-diag}(\overline{\xi}_a)\times\overline{A}_i + \mu\times\overline{A}_i + \alpha\overline{I}\text{-}\gamma\times\overline{A}_i \quad (21)$$

$$\overline{B}_{i+1} = \overline{B}_i\text{-diag}(\overline{\xi}_b)\times\overline{B}_i + \mu\times\overline{B}_i + 0\text{-}\gamma\times\overline{B}_i \quad (22)$$

taking into account the condition of preventing the economic agent bankruptcy:

$$\begin{aligned}&(\mu-\xi_m)\times a_m + \alpha - \gamma(a_m) = 0,\\ &\alpha = a_m[\mu - \xi_m - \gamma]\end{aligned} \quad (23)$$

Then the change in the capital of economic agents becomes as follows:

$$\begin{aligned}Q_{i+1} &= Q_{a_i} - \overline{A}_i^T\overline{\xi}_a + \mu Q_{a_i} + \alpha\mu - \gamma Q_{a_i} + \\ &+Q_{b_i} - \overline{B}_i^T\overline{\xi}_b + \mu Q_{b_i} + Q - \gamma Q_{b_i} = \\ &= Q_i + Q_i(\mu - \langle\xi\rangle) - \gamma Q_i + \alpha\mu\end{aligned} \quad (24)$$

Hence follows:

$$\frac{\triangle Q_i}{Q_i} = (\mu\text{-} <\xi>)\text{-}\gamma + \frac{m\times a_m(i)}{Q_i}[\mu\text{-}\xi_{max}\text{-}\gamma] \quad (25)$$

If $\frac{m\times a_m(i)}{Q_i}$ is a small quantity, then the capitalization of the worst economic agent will be significantly less than the average $m\times a_m \ll \overline{A}_i^T\overline{I}$. This means that the formula (25) defines the minimum requirements for the tax addition, which are almost always implemented. Consequently, the direct budget support, required for the normal economic agent activity within the framework of a dynamic probabilistic model, looks fundamentally better than using the merit order pricing mechanism [5-7, 9].

If it is impossible to abandon the merit order pricing for technological reasons, it is possible some economic agents exit the power generation and supply market, which is reflected in the model by the appearance of d-agents that are neutral to the Δc-shift.

$$\overline{A}_{i+1} = \overline{A}_i - \text{diag}(\overline{\xi}_a)\overline{A}_i + \mu\overline{A}_i + \Delta c\times\overline{A}_i \quad (26)$$

$$\overline{B}_{i+1} = \overline{B}_i - \text{diag}(\overline{\xi}_b)\overline{B}_i + \mu\overline{B}_i - \triangle c\times\overline{B}_i \quad (27)$$

$$\overline{D}_{i+1} = \overline{B}_i - \text{diag}(\overline{\xi}_d)\overline{B}_i + \mu\overline{D}_i \quad (28)$$

Then:

$$Q_{i+1} = Q_i - <\xi> Q_i + \mu\overline{Q}_i - \triangle c\times\frac{\overline{Q}_i^T\text{-}Q_{a_i}}{Q_i} \quad (29)$$

when $Q_{i+1} - Q_i \geq 0$

Accordingly, the economic system's development becomes implemented with relaxed requirements for the value of $\triangle$ c at significant Q_i.

VI. CONCLUSION

The digitalization of the Russian economy makes it possible to use the dynamic probabilistic model developed by the authors within the framework of the development of the market theory of economic systems to analyze the development of individual industries and economic agents, taking into account their systematic and random internal and external interaction.

The analysis of the marginal mechanism of quasi-market pricing, carried out within the framework of the dynamic probabilistic model of the economic system's development, used in the Russian electric power industry, showed that there is a deceleration of the growth of the economic system as a whole even with small movements from the weighted average estimates. This confirms the assessment of the negative impact of the merit order pricing mechanism on the development of the economic system as a whole.

If it is necessary to preserve inefficient economic entities that produce electric power, it is preferable to use direct budget support while maintaining the market price.

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