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

Ivan D. Grachev
Laboratory of simulation modeling of the interaction of economic objects
Central Economics and Mathematics Institute RAS
47, Nakhimovsky prospect, Moscow, Russia
idg19@mail.ru

Sergey N. Larin
Laboratory of simulation modeling of the interaction of economic objects
Central Economics and Mathematics Institute RAS
47, Nakhimovsky prospect, Moscow, Russia
sergey77707@rambler.ru

Nina M. Baranova
Department of economic and mathematical modeling
Peoples’ Friendship University of Russia (RUDN University)
6 Miklukho-Maklaya Street, Moscow, 117198, Russia
e-mail: baranova_nm@pfur.ru

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 \( a_i \) is used as characteristic of each economic agent and \( \xi_j \) 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]:

\[
\bar{A}_{i+1} = \bar{A}_i \cdot \text{diag}(\xi_j) \cdot \bar{A}_i + \frac{A_i^T \xi_i}{A_i^T + \mu} \cdot \bar{A}_i
\]

\( i \) – cycle number;

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

\( I \) – unit vector;

\( \bar{\xi}_j \) – normalized vector of the cost price by j-agents;

\[
[\frac{A_i^T \xi_i}{A_i^T + \mu}] = <\xi>_A – «capital» averaging, i.e. transactions weighted average by capital.
\]

\[
[A]_i = a_j
\]

\[
[\bar{E}]_i = \bar{\xi}_j
\]

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 \( \bar{\xi}_j \).

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):

\[
\bar{A}_{i+1} = \bar{A}_i \cdot \text{diag}(\xi_j) \cdot \bar{A}_i + \frac{A_i^T \xi_i + \bar{P}_1 \mu}{A_i^T + \mu} \cdot \bar{A}_i
\]

\[
\bar{P}_{i+1} = \bar{P}_i - \bar{P}_1 \cdot \mu + \frac{A_i^T \xi_i + \bar{P}_1 \mu}{A_i^T + \mu} \cdot \bar{P}_1
\]

\( \bar{P}_1 \) – resources available to market agents;

\( \mu \) – 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:

\[
<\mu> <\xi> = \frac{A_i^T \xi_i}{A_i^T + \mu}
\]

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):

$$P_i \gg \tilde{A}_1^T \times I = Q_i$$  (7)

$Q_i$ – total capital of the economic system.

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

$$\tilde{A}_{i+1} = \tilde{A}_i - \text{diag}(\xi_i) \times \tilde{A}_i + \mu \tilde{A}_i$$  (8)

It should be noted that there are

$$<\xi_{i+1}> < <\xi_i> \ll \mu <\xi>$$  (9)

and uncorrelated residuals

$$<\tilde{\xi}_i>\text{diag}(\tilde{\xi}_i^2)$$  (10)

$\tilde{\xi}^2$ – variance matrix,

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

$$Q_i(i) = Q_i(i) \cdot \exp((\mu-<\xi_i>)I)$$  (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 ($\tilde{A}$) and power consumers ($\tilde{B}$). Then the formula (8) is modified as follows:

$$\tilde{A}_{i+1} = \tilde{A}_i - \text{diag}(\tilde{\xi}_i) \times \tilde{A}_i + \mu \tilde{A}_i$$  (12)

$$\tilde{B}_{i+1} = \tilde{B}_i - \text{diag}(\tilde{\xi}_i) \times \tilde{A}_i + \mu \tilde{B}_i$$  (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 $\Delta c$, which guarantees the last producer-agent $m$ a non-negative value of the change in his capital at the $i$ step.

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

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

$$\tilde{A}_{i+1} = \tilde{A}_i - \text{diag}(\tilde{\xi}_i) \times \tilde{A}_i + \mu \tilde{A}_i + \Delta a_{\tilde{A}_i}$$  (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):

$$\tilde{B}_{i+1} = \tilde{B}_i - \text{diag}(\tilde{\xi}_i) \times \tilde{B}_i + \mu \tilde{B}_i - \Delta c \cdot \tilde{B}_i$$  (16)

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

$$Q_{iri} Q_i = \tilde{A}_i^T \mu \tilde{A}_i^T \left( \tilde{A}_i \tilde{\xi}^T \right) + \Delta c \tilde{A}_i^T I + \Delta c \tilde{B}_i^T I = (17)$$

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

$$\mu - <\xi> - \Delta c \times \frac{\tilde{B}_i^T \tilde{A}_i^T I}{Q_i} \geq 0$$  (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):

$$0.05 - \Delta c \times 0.8 \geq 0$$  (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:

$$\Delta c \equiv 0.06$$  (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 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):

\[ \bar{A}_{i+1} = \bar{A}_i - \text{diag}(\xi_i) \cdot \bar{A}_i + \mu \bar{A}_i + \Delta c \times \bar{A}_i \]  
(21)

\[ \bar{B}_{i+1} = \bar{B}_i - \text{diag}(\xi_i) \cdot \bar{B}_i + \mu \bar{B}_i + 0 \times \gamma \times \bar{B}_i \]  
(22)

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

\[ (\mu - \xi_m) \times a_m + \alpha - \gamma (a_m) = 0, \]  
(23)

\[ \alpha = a_m \left[ \mu - \xi_m - \gamma \right]. \]

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

\[ Q_{i+1} = Q_i - \bar{A}_i^T \xi_a + \mu Q_{a_i} + \alpha \mu - \gamma Q_{a_i} + 
\]

\[ \rightarrow Q_i - \bar{B}_i^T \xi_a + \mu Q_{b_i} + Q - \gamma Q_{b_i} = 
\]

\[ = Q_i + \left[ \mu - (\xi) \right] - \gamma Q_{a_i} + \alpha \mu \]  
(24)

Hence follows:

\[ \frac{\Delta Q_i}{Q_i} = (\mu - \xi \gamma) + \frac{\text{max}(\xi)}{Q_i} \left( \mu - \xi \gamma \right) \]  
(25)

If \( \frac{\text{max}(\xi)}{Q_i} \) is a small quantity, then the capitalization of the worst economic agent will be significantly less than the average \( \text{max}(\xi) \ll \bar{A}_i \bar{I} \). 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 \( \Delta c \)-shift.

\[ \bar{A}_{i+1} = \bar{A}_i - \text{diag}(\xi_d) \bar{A}_i + \mu \bar{A}_i + \Delta c \times \bar{A}_i \]  
(26)

\[ \bar{B}_{i+1} = \bar{B}_i - \text{diag}(\xi_d) \bar{B}_i + \mu \bar{B}_i - \Delta c \times \bar{B}_i \]  
(27)

\[ \bar{B}_{i+1} = \bar{B}_i - \text{diag}(\xi_d) \bar{B}_i + \mu \bar{B}_i + \mu \bar{B}_i - \Delta c \times \bar{B}_i \]  
(28)

Then:

\[ Q_{i+1} = Q_i - \xi > Q_i + \mu Q_i - \Delta \times \frac{Q_i}{Q_i} \]  
(29)

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

Accordingly, the economic system’s development becomes implemented with relaxed requirements for the value of \( \Delta c \) 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.

References

[1] N.I. Voropay, G.I. Sheveleva, Features and growth prospects for the development of corporate governance in the Russian electric power industry, Management of Large-Scale System Development (MLSD’2017), 2017, pp. 33–45.

[2] H.K. Brondbo, A. Storebo, T.K. Boomsera et al, A real options approach to generation capacity expansion in imperfectly competitive power markets, Energy Syst., 2020, vol. 11, pp. 515–550, https://doi.org/10.1007/s12667-019-00325-3

[3] W.F. Sharp, G.J. Alexander, J.V. Bailey, Investments, 6th ed, 2016, 1040 p., ISBN-13: 978-0130101303

[4] Ministry of Energy of Russian Federation, The main characteristics of the Russian electric power industry, 2019. URL: https://minenergo.gov.ru/en/activity/statistic Accessed 10 August 2020

[5] C. Zhang, L. Sun, F. Wen, Z. Lin, G. Ledwich, & Y. Xue, An interpretative structural modeling based network reconfiguration strategy for power systems, International Journal of Electrical Power & Energy Systems, 2015, vol. 65, pp. 83–93.

[6] N.M. Baranova, N.A. Shevtsova, & E.G. Dmitrieva, Industrial policy as a tool of restructuring the Russian economy, In V. Mantulenko (Ed.), International Scientific Conference “Global Challenges and Prospects of the Modern Economic Development”: The European Proceedings of Social & Behavioural Sciences, London: Future Academy, 2019, vol. 57, pp. 1877–1887, DOI: 10.15405/epubs.2019.03.191

[7] B.S. Sergi (Ed.), Modeling economic growth in contemporary Russia, Harvard University, USA: Emerald Publishing Limited, 2019.
[8] A. Zambrano, Motivating informed decisions, Econ. Theory, 2017, vol. 67, pp. 645-664, https://doi.org/10.1007/s10878-015-0139-8

[9] B.S. Sergi (Ed.), Exploring the future of Russia’s economy and markets: Towards sustainable economic development, Bingley: Emerald Publishing Limited, 2018.

[10] M. Magnusson, L. Jonsson, & M. Villani DOLDA, A regularized supervised topic model for high-dimensional multi-class regression, Comput Stat, 2020, vol. 35, pp. 175–201, DOI: https://doi.org/10.1007/s00180-019-00891-1

[11] U. Stridbeck et al, Electricity Market Experience: Lessons from liberalised electricity markets International Energy Agency, France: Cedex, 2005, p. 274

[12] I.D. Grachev, The market probabilistic-statistical model. The methodology and econophysical tools for modeling economic progress, Germany, Saabrucken: Lambert Publishing House, 2011, 340 p.

[13] I.D. Grachev, I.V. Nekolin, The innovation activity and economic growth, Innovations, 2019, No 8 (250), pp. 3-8.

[14] I.D. Grachev, S.N. Larin, N.A. Sokolov, Application of modern digital tools for choosing a strategy for the development of economic entities, Economics and Entrepreneurship, 2020, vol. 14, No. 1 (114), pp.1132-1136.

[15] A.V. Polbin, S.M. Drobyshevsky, Dynamic stochastic general equilibrium model construction for the Russian economy, Moscow: Gaidar Institute for Economic Policy, 2014, 156 p.

[16] J.Y.L. Boudec, et al, Fourth Int. Conf. on the Quantitative Evaluation of Systems (QEST), UK: Edinburgh, 2007, pp. 3–18, doi: 10.1109/QEST.2007.9

[17] J.M. Lasry, and P.L. Lions, Mean field games Japan, J. of Mathematics, 2007, vol. 2, pp. 229-260, https://dx.doi.org/10.1007/s11537-007-0657-8

[18] G.B. Asheim, T. Mitra, Characterizing sustainability in discrete time, Econ Theory, 2020, https://doi.org/10.1007/s10878-019-0020-0

[19] K.J. Wu, M.L. Tseng, A.S. Chiu, & M.K. Lim, Achieving competitive advantage through supply chain agility under uncertainty: A novel multi-criteria decision-making structure, International Journal of Production Economics, 2017, vol. 190, pp. 96–107.

[20] L. Wang, L. Ma, K.J. Wu, A.S. Chiu, & S. Nathaphan, Applying fuzzy interpretive structural modeling to evaluate responsible consumption and production under uncertainty, Industrial Management & Data Systems, 2018, vol. 118(2), pp. 432–462.

[21] A. Pilipenko, & Z. Pilipenko, Shocks in global economy: Impulse model of macroeconomic cycle, In S. Bruno, M. Zioolo (Eds.), Regaining Global Stability After the Financial Crisis. Pennsylvania, USA: IGI Global, 2018, pp. 238-256.

[22] S. Vinodh, K. Ramesh, & C.S. Arun, Application of interpretive structural modelling for analysing the factors influencing integrated lean sustainable system, Clean Technologies and Environmental Policy, 2016, vol. 18(2), pp. 413–428.

[23] R.K. Singh, S. Modgil, & P. Acharya, Assessment of supply chain flexibility using system dynamics modeling, Global Journal of Flexible Systems Management, 2019, vol. 20(sup1), pp. S39–S63.

[24] N. Sharma, B.S. Sahay, R. Shankar, & P.R.S. Sarma, Supply chain agility: Review, classification and synthesis, International Journal of Logistics Research and Applications, 2017, vol. 20(6), pp. 532–559.

[25] M.S. Sangari, J. Razmi, & S. Zolfaghari, Developing a practical evaluation framework for identifying critical factors to achieve supply chain agility, Measurement, 2015, vol. 62, pp. 205–214.

[26] S.K. Mangla, P. Kumar, & M.K. Barua, Flexible decision approach for analysing performance of sustainable supply chains under risks/uncertainty, Global Journal of Flexible Systems Management, 2014, vol. 15(2), pp. 113–130.

[27] M. Kim, & S. Chai, The impact of supplier innovativeness, information sharing and strategic sourcing on improving supply chain agility: Global supply chain perspective, International Journal of Production Economics, 2017, vol. 187, pp. 42–52.

[28] D. Eckstein, M. Goellner, C. Blome, & M. Henke, The performance impact of supply chain agility and supply chain adaptability: The moderating effect of product complexity, International Journal of Production Research, 2015, vol. 53(10), pp. 3028–3046.

[29] K. Govindan, S. Seuring, Q. Zhu, & S.G. Azvedo, Accelerating the transition towards sustainability dynamics into supply chain relationship management and governance structures, Journal of Cleaner Production, 2016, vol. 112, pp. 1813–1823.

[30] R.A. Bithandi, & C. Valmohammadi, Effects of supply chain agility on profitability, Business Process Management Journal, 2017, vol. 23(5), pp. 1064–1082.

[31] M.D.A. Al-Shboul, Infrastructure framework and manufacturing supply chain agility: The role of delivery dependability and time to market, Supply Chain Management: An International Journal, 2017, vol. 22(2), pp. 172–185.