Implementation of market methods of price forming in the field of power industry with the application of the consolidated balance-market model of economic systems

I D Grachev[1], S A Nekrasov[2], S N Larin[3], N V Noack[4] and N M Baranova[5]

[1]Dr.sc.oec., Chief Researcher, e-mail: idg19@mail.ru, ORCID: 0000-0003-1815-5898
[2]PhD in Technical Sciences, Senior Researcher, e-mail: san693@mail.ru, ORCID: 0000-0002-7649-0515
[3]PhD in Technical Sciences, Senior Researcher, e-mail: sergey77707@rambler.ru; ORCID: 0000-0001-5296-5865
[4]PhD in Psychological Sciences, Leading Researcher, e-mail: n.noack@mail.ru; ORCID: 0000-0001-8696-5767

Central Economics and Mathematics Institute RAS, 47, Nakhimovsky prospect, 117418 Moscow, Russia

[5]PhD in Pedagogic Sciences, Associate professor, Department of Economic and Mathematical modeling, Peoples' Friendship University of Russia (RUDN University), 6, Miklukho-Maklaya Str., 117198 Moscow, Russia, e-mail: baranova_nm@pfur.ru; ORCID: 0000-0002-7201-9435

Abstract.
Object. The power industry of Russia is being developing with the use of its natural resources, advanced ideas, implementation of existing opportunities. So, the key task of the energy strategy of Russia till 2035 is the transfer from the commodity-heavy to the resource-innovative development of both the power industry and the economics of the country. All conditions have been created for its solution as of now – the power industry is expected to increase by 20-25% if demand for the hydrocarbon raw materials falls on the immediate horizon.

In this juncture such branch as the power industry seems to be a crutial and sophisticated object of the research on the dynamics of economic systems infrastructural transformations. Anyway, its implementation in the field of the power industry involved quasi-market mechanisms of the preservation of existing ones and the building of new non-competitive powers with the use of such mechanisms as "adhesion contract" and "marginal price forming".

The work shows the inhibiting impact of these mechanisms on the economic system. The offer for its replacement to increase the pace of the power industry development and of the Russian economics substantiates.

The research purpose is to substantiate the application of the consolidated balance-market model of economic systems for the analysis of the dynamics of the development of the technologically heterogenic branch, interacting with the other economic system, provided Leontief correlations. The power industry was selected as the studied one. Peculiarities of the reforming of power price rates, combining both market and regulating (quasi-market) mechanisms, were considered.

Methods. The random balance-market model became the methodologic basis for mixed economic systems in the option of the self-consistent field of Leontief matrices. It make it possible to solve practical issues of the development of most important multi-agent branches in its interaction with the other economic system. In the work this model is applied in the quasitensor form for the evaluation of mixed mechanisms of the regulation of price rates in the power industry.

Results. It was revealed that the common use of such mechanisms as "marginal price forming" and "adhesion contracts" fully suppresses the economic growth in all branches of economics. In order to find the way out was offered the consolidated random model of mixed economic

systems in the quasitensor form. Its application will make it possible to obtain the new distribution of the capital by goods and agents with the better use of its technical advantages with such level of power rates.

Conclusions. The possibility of the subtle analysis of the dynamics of the specialization and localization of agents was shown for the following development of distributed centralized energoinformational systems in the Russian Federation. It is expedient to use offered approach and developed algorithms of modeling for the evaluation of the accelerated economic growth of other key branches of the Russian economics.

Key words: mixed economic systems, power branch, market and quasi-market mechanisms, regulation of rates, random balance-market model, Leontief matrices, self-consistent field

1. Introduction

The authors developed a probabilistic model of mixed economic systems. In it, the market is modeled by a self-consistent field of market values or other quasi-tensor parameters characterizing the economic system in a multidimensional economic space [1, 2].

It allowed us to effectively solve a wide range of problems: fundamental issues of modeling the innovative generation of Kondratieff cycles, the bitcoin course and the prospects of cryptocurrencies.

In this juncture the special case of the model with the self-consistent field of Leontief matrices, allowing to analyze the development of branches with the mixed competitively regulated management in its interaction with the other part of the economic system is of considerable interest [3].

The electricity field appears an important and comfortable object for studies of economic systems [4-5], where within frames of "market" reforms are implemented quasi-market mechanisms for the preservation of existing and building of new non-competitive capacities with use of mechanisms of so called "marginal price forming" and "adhesion contracts" [6].

In the practical aspect the timeliness of terms of reference and of the solving of this task is referred to the digitalization of Russian economics, which principally allow to form any types of Leontief matrices, namely, specific two good matrices of "power energy-everything else" type. Anyway, the expedience and efficiency of such use of the digital information requires both the theoretic and model processing of the problem for the branch, which is of interest to us. Certain approaches to the solution of mentioned problems will be disclosed in this article.

2. Research purpose

The purpose of this work is to substantiate the possibility of the application of the consolidated balance-market model of economic systems for the analysis of the dynamics of the development of the technologically heterogenic branch, interacting with the remaining economic system, provided Leontief correlations at the example of the reformation of the electric power industry, combining both market and regulating mechanisms of such type as marginal price forming and adhesion contracts.

3. Materials and methods

Nowadays, reforms of the electric power industry enter its final lap. So, we can be confident enough that along with positive results of its implementation there are also obvious unsatisfactory results [7]. To most significant of latter ones following ones can be referred.

1. Number of employees has been doubled at the expense of the number of different kinds of intermediates with annual generation volumes, equivalent to the former RSFSR epoch.

2. The number of hours of use of capacities has been considerably reduced.

In this context the modern Russia has lost its leading positions. Before the dissolution of the Soviet Union, for example, stations of its energetic system have been working better than any ones in the world, regularly showing the use of capacities up to 6 thousand and more hours. Anyway, for the electric power reform Russia has followed the example of tough US states, at which power stations the use of capacities was not exceeding 4.5 thousand hours. As a result today we have got the opposite pattern: best countries in the world near by the number of hours of capacities to Soviet results, and the Russia's index is about 4.5 thousand hours, as of underdeveloped countries [8].

3. With different kinds of calculation by kWh, the accidence in the Russian electricity industry has grown in 1.5-2 times.

All these facts are well known and obvious, which should be purposively worked out in order to obtain its improvement.

As to use of mechanisms of the so called "marginal pricing" (MP) and «capacity connection agreement» (CCA) everything is much more difficult. These mechanisms are oriented to the support of the functioning of existing and the building of new non-competitive stations for safety reasons and the whole range of other factors due to the shift of the electric power price above its equilibrium value [9].

For clarity let's show the simple example, when within CCA frames 1.7 GW of the regeneration for the amount of $857 mn. In comparison with the reserve foundation of the country and of amounts, annually going to the budget proficit, this figure is not comparable marginally. Anyway, from the point of view of the theory and practice even this minor amount exactly shows the amount of the mechanism itself. The explication of all provisions of the theory and of its practical interpretation will take a lot of place, but the essence of the mechanism will not change in this juncture and will be very simple – the minor amount will be equivalent to the price shift, which will be significant enough.

So what is the essence of the CCA mechanism? To be simple, its use will cause the increase of the electricity price in comparison with its average value. For example, let's take the building of about 4 GW, which have been distributed in conformity with CCA mechanism within a year. Let's multiply this figure on the average cost of the building of one GW and let's compare it with total volumes of power sales at the national wholesale market. As a result of these simple calculations it will be found out, that the power price shift will be about 10% upwards from its average value. At the first sight we can see the increase of the visible power efficiency.

But the main problem is that the power is used almost in all branches. Of course, there are export hydrocarbon branches, which do not strongly depend from power prices. But we hardly can highlight many such branches, as most of it strongly depend from power prices. So it happens that the power price increase stipulates the growth of prices for the production, manufactured in other branches, where it is being used. So, possibilities of the growth of these areas are being drastically downshifting.

We can analyze this situation in more details, while using the concept of self-consistent Leontief matrices. Anyway, as it will require new mathematic formulations, first of all we will build evaluations, reflecting the essence of the studied problem with lowest terms of the option, provided endless resources and identic agents, which we have already successfully applied in digital economic-epidemic models [11-15]. That's how it looks at the graph below (figure 1).
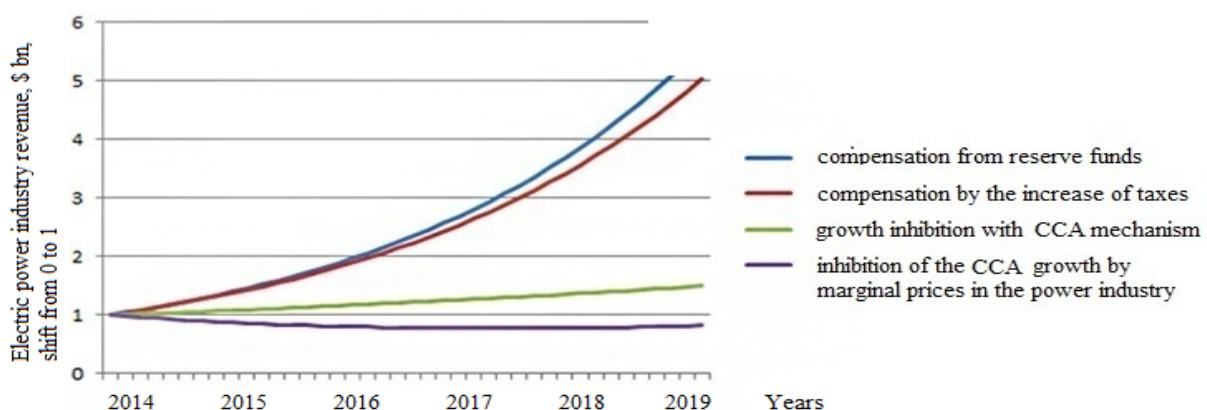

Figure1. Simplified option of the impact of CCA and MP mechanisms on the branch economic growth

Source: estimated by the authors

The first upper curve is typical for objects of Zainskaya State District Power Station (SDPS) like objects, which really needs modernization with use of reserve funds. The modernization of such kind infrastructure objects of the power system of the country requires about 4 bn USD. Provided that annually about 100 bn USD are forwarded to the sovereign welfare fund of Russia, which is the successor of the former stabilization fund, as well as the partially unused budget proficit, the mentioned figure seems rather minor. But with that it can provide for the economics growth of about 4-5% [15-19].

The second curve shows the case, when the modernization of sites like Zainskaya SDPS will not require the sovereign wealth fund, which is placed in other countries and creates certain losses for the country, as well as will be used funds, received at the expense of the increase of taxes in all areas, including exporters of hydrocarbon raw materials. Let's increase by above mentioned 4 bn USD the amount, required for the modernization of the branch infrastructure and minor for the whole branch due to the tax return. The result is that this approach reduces the economic growth by a negligible margin [20-35].

The third curve shows how the CCA mechanism goes, when the power price grows a little, for about 10%. Anyway, the result is the cardinal suppression of the economic growth.

The lower curve shows what is going on with the simultaneous use of the whole scope of both CCA and marginal price forming mechanisms. The main difference here is that the use of the CCA mechanism assumes the building of new stations and the use of the marginal price forming mechanism assumes the increase of the price in order that some unprofitable, but already existing stations continue working. The joint use of these mechanisms fully suppresses the initial five per cent economic growth. So, is evident the impact of one of most powerful mechanisms of the suppression of the economic growth in the country. Accordingly, the combination of such mechanisms (CCA and MP) together with the regulation of the key rate, overestimated taxes and the indefinitely reinforced ruble, that's what the Central Bank of Russia is being doing, what is rather sufficient in order to fully suppress not only the economic growth of 3-5%, but also 8-10% growth, which has been recently demonstrated by China [12].

Intermediate result: we need to correct the current situation with the electric industry on a timely basis, as CCA and MP mechanisms considerably hinder the activity of all consumers of the electric power [13]. In fact, in order to principally improve the position of all consumers of the electric power it is enough to use the direct budget support or to directly involve national welfare funds.

4. Results and discussion

For the more full analysis, which will have practical prospects, as the digitalization provides the necessary experimental information, we will use the consolidated balance-market model of mixed economic systems, which has been developed by us [1-2] and which contains both fundamental, derived from physical, chemical and other correlation laws (ore-coal-iron), as well as situational technologic correlations between branches, which looks like this in the simplest price record:

$$\bar{P} = L \times \bar{P} \qquad (1)$$

$\bar{P}$ - is the vector of prices for m-goods

L - Leontief matrix in the price record

The work [2] offers the idea of averaged Leontief balances, allowing to in-build the market chaos into Leontief balances by choosing a certain averaging mechanism, corresponding to the two hundred year practice of evaluation activities.

In fact, all real economics are mixed [14, 15], it really simultaneously contains a variety of cardinally different Leontief balances. In its logical end this uncontested fact makes it possible for each agent (j) to assign the individual Leontief matrix $L(j)$, corresponding to the idealized situation of the replacement of all agents, acting with equivalent goods, by j-type agents with its peculiar individual technologies.

The work [2] shows, that if the consolidate Leontief matrix shows up as "capitalist" averaging out of individual $L(j)$ – Leontief matrices of agents, then it corresponds to the standard determinist one. It

also shows that goods' prices, equal for it averaged Leontief matrix, coincide with market costs in its classic determination by practitioners and theoreticians of evaluating activities [16, 17, 18].

So, we have schematically in-built the statistic ensemble of agents with considerably different technologies of activities in scheduled Leontief balances within a fixed time period (*i*). In order to obtain a working dynamic model we need to describe, how the interaction of agents (*j*) inside the Leontief cycle $i \to i+1$ causes the redistribution of the capital between them, consequently, to the change of coefficients in the capitalist averaging, what is equivalent to the endogenous change of the most averaged Leontief matrix etc.

The complexity of the front solution of this task is obvious for everyone, who is familiar with the problem of many bodies in physics and mathematics, which, starting from already three bodies, first of all, has not got a common analytic solution, and, secondly, for multitudinal systems it causes such problems as instability of computer computations [19]. If we take into consideration, that the interaction of agents in economics is much more sophisticated than in physics, there are evident complications, arising with the choice of such an approach to its solution.

Anyway, physics itself suggests the possible outcome from this complication in the form of the concentration of the self-consistent field [20]. Without giving specifics, let's highlight, that the concept of the self-consistent field determines the dynamics in the *i*-moment for the *j*-particles by its interaction with the summary (self-consistent) field, created by all other particles in the point of the *j*-particle, getting rid of the reliably inaccurate count of numerous pairwise interactions [21].

This concept is quite natural for real economics. In fact, when you comes to the market to order to purchase apples, you really do interact at a certain counter not with a certain vendor, who, when coming to the market, becomes unfree in its transactions, is included in his "cooperative effects", but with the market itself and with its averaged evaluations of the demand and offer.

The key dimension of the market, around which can be built the initial concept of the self-consistent field, is the market cost, which in two hundred years theory and practice of the evaluation activities [16, 18] is determined as the most probable price of the object and is determined by the practically weighed, by involved capitals, averaging by transactions with equivalent sites.

It should also be pointed out, that independent professional evaluators, while carrying out the total evaluation of the real estate in cities, while carrying out equivalent transactions, are, basically, using the field methodology, while "weighing" objects, geographically remote from the center of the city and of it other "poles", while introducing the dependence of the market price from the set of distances to "poles".

According to Leontief, at the first step of the model building let's limit oneself by market prices, homogenous in the geographic and other kinds of market prices. While synchronizing following actions with the object (goods) by the special case of the "release of goods", we will obtain the result of the interaction of *j*-agents at the *i*-cycle in the one goods approach as [22, 23]:

$$\bar{A}_{i+1} = \bar{A}_i - diag\left(\bar{\xi}_i\right) \times \bar{A}_i + \frac{(\bar{A}_i^T \cdot \bar{\xi}_i)}{(\bar{A}_i^T \cdot \bar{I})} \times \bar{A}_i \qquad (2)$$

$\bar{A}$ – vector of the capital distribution by *j*-agents at *i*-cycle

$\bar{I}$ – single vector

$\bar{\xi}_i$ – normalized vector of the self-cost of manufacturing of goods by *j*-agents

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

The mathematic kind of the formula (2) is the simplest rule of any market – «if you work worse than the average market – you lose the capital, if you work better – you purchase the capital» at the each $i \to i+1$ cycle.

The scheme of the combination of Leontief balances (1) and of the market redistribution of capitals by (2) in the self-consistent field of market costs is offered in [2]. Below is given the scheme of the quasitensor consolidate model, consolidated for the case "every agent manufactures any goods", which form is convenient for the following computer modeling (3).

$$A(i+1,j,k) = A(i,j,k) - \xi(i,j,k) \times A(i,j,k) + \frac{\sum_j^m A(i,j,k) \times \xi(i,j,k)}{\sum_{j=1}^m A(i,j,k)} \times A(i,j,k) \tag{3}$$

Current individual Leontief matrices (technologic receipts) give individual Leontief prices (self-cost) of the j-agent in conformity with the common Leontief scheme (4).

$$P(i,j,k) = \sum_{l=1}^m L(i,j,k,l) \times P_0(i,l) \tag{4}$$

For formulas (3), (4):

i – time (cycles) index, j – index of agents, $\{k,l\}$ – branch indices of Leontief matrices $L(i,j)$;

$L(i,j,k,l)$ – individual of the Leontief matrix of the j-agent at the i-cycle, i.e. this is the number of units of goods (e), necessary for the production of goods to (k) (j)-agent at the (i)-cycle;

$P_0(i,k)$ – starting prices for the i-cycle of all k-goods (possible and non-equilibrium);

$A(i,j,k)$ – starting for the i distribution of the capital by the j-agent for the release of k-goods;

$\xi(i,j,k)$ – relative deviation of the "self cost" from the capitalist averaging, which detailed option will be determined below;

$P_0(i,l)$ – starting market prices for goods at the entry to the i-cycle.

The formula (3) is immediately limited to the standard Leontief one (1) by the removal of the dependence from i and j, i.e. the transfer to technologically identical agents. The transfer to the each certain case (each j-agent is dealing with the release of one good) is carried out by the resetting of all other positions in the quasitensor $A(i,j,e)$.

The vector of the self-consistent field of market costs $< P(i,k) >_A$ (5) is, as earlier, the "capitalist" averaging, i.e. the convolution by j-index with $A(i,j,k)$:

$$< P(i,k) >_A = \sum_{j=1}^m A(i,j,k) \times P(i,j,k) \times \left(\sum_{j=1}^m A(i,j,k) \right)^{-1} \tag{5}$$

And after each technologically individual agent interacts with the vector self-consistent field of market costs in conformity with the same rule «worse than the market» – you lose the capital, «better than the market» – you acquire the capital.

Technically, for the use of worked out algorithms let's use the three index matrix (6) of relative deviations of individual prices from self-consistent ones.

$$\xi(i,j,k) = \frac{P(i,j,k) - P_s(i,k)}{P_s(i,k)}; \quad P_s(i,k) \cong < P(i,k) > \tag{6}$$

And when the Leontief autoprogress cycle is reduced to the redistribution of the capital by all agents j and goods k provided its individual technologic Leontief matrices.

We got new version of capital allocation by goods and agents that increases its technological benefit under existing price level.

We introduce external data for nonzero growth of the sum $\sum_{j,k}^{n,m} A(j,i,k)$) instead of $P(0,l)$ [16]. Then we enter update on current market prices $P_s(i,l)$ into equation (1) instead of $P(0,l)$ and repeat the equation (3) for $A(i+1,j,k,e)$.

A two-product model of "power - everything else" is presented to illustrate the algorithm [21]. The actual spread in own needs of power and remaining items producers is used as basis when constructing the model of two-industry Leontief matrices. In its simplest version it leads to the model matrix (7)-(9):

$$L(j) = LE \times j + LV(1 - j / N) \tag{7}$$

$$LE = \begin{bmatrix} 0,1 & 0,03 \\ 0,9 & 0,97 \end{bmatrix} \tag{8}$$

$$LV = \begin{bmatrix} 0,2 & 0,1 \\ 0,8 & 0,9 \end{bmatrix} \tag{9}$$

Approximated matrices LE, LV are built on the basis of evaluations of the dispersion of power costs for own needs of Russia generation, as well as shares of the electrical energy industry in the GDP of Russia [24]. Its detailing requires the collection of the digital information from the whole generation of Russia.

The absence of training of agents in the course of Leontief cycles as well as the uniform start distribution of capitals by agents and goods.

The figure 2 shows the logarithmical scale of the growth dynamics, as well as "specializations" of electric power manufacturers (left wing) and of other goods (right wing) with its link only through Leontief correlations.
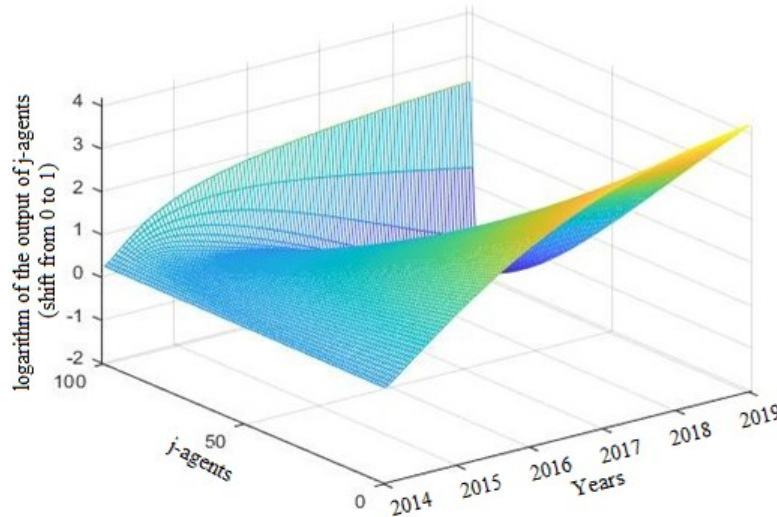

Figure 2. Growth dynamics and "specializations" of manufacturers of the power energy (left wing) and of other goods (right wing) with its connection exclusively through Leontief correlations.
Source: estimated by the authors [25]

The figure 3 shows the logarithmic scale of the integral dynamics of the economic growth of such a system. The same model with the included marginal price forming is shown at figures 4 and 5. Figures 2-5 show the obvious and unjustified redistribution of the capital in favor of agents – manufacturers of the electric power with the suppression of the economic growth of all other branches and of the whole economic system of the country.

5. Conclusions

The digitalization of the Russian economics provides the opportunity for the application of the consolidate balance-market theory of economic systems, developed by authors, provided its systemic and random internal and external interaction. In the work such an opportunity is practically implemented for the "two goods" system – "electric power – everything else".
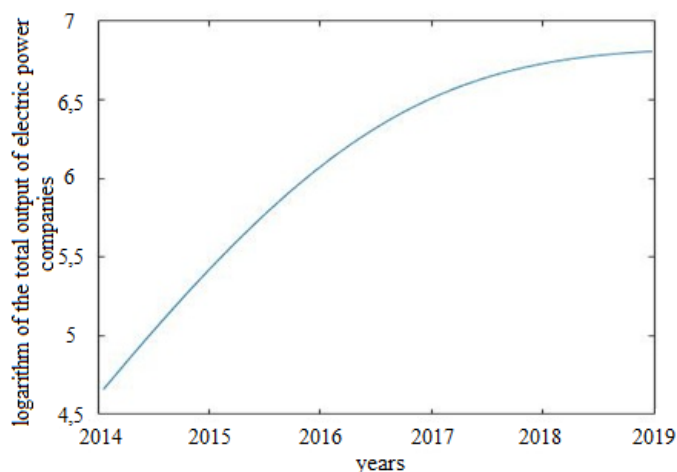

Figure 3. Integral dynamics of the economic growth of the system, represented at figure 2.
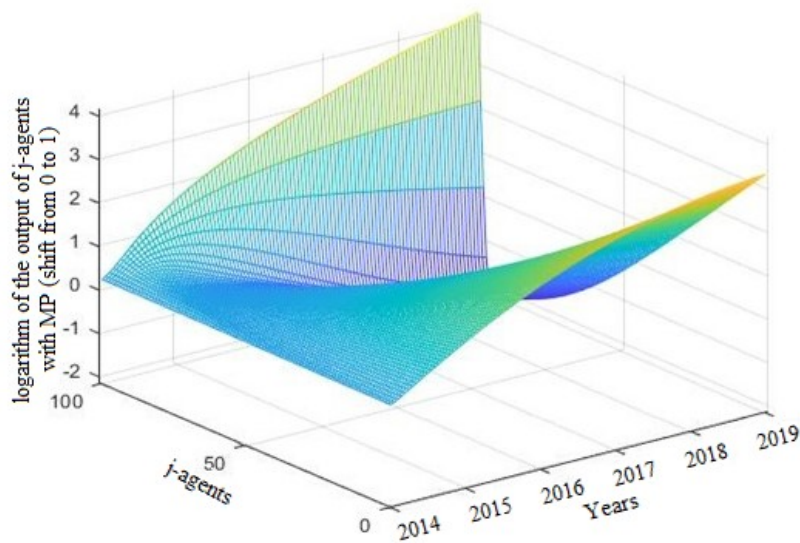**Source**: estimated by the authors [25]

Figure 4. Growth dynamics and "specializations" of manufacturers of the power energy (left wing) and of other goods (right wing) with its connection exclusively through Leontief correlations with the inclusion of the marginal price forming. **Source**: estimated by the authors [25]

Was confirmed the evaluation of the suppression influence of mechanisms of the marginal price forming and of adhesion contracts for the whole economic system.
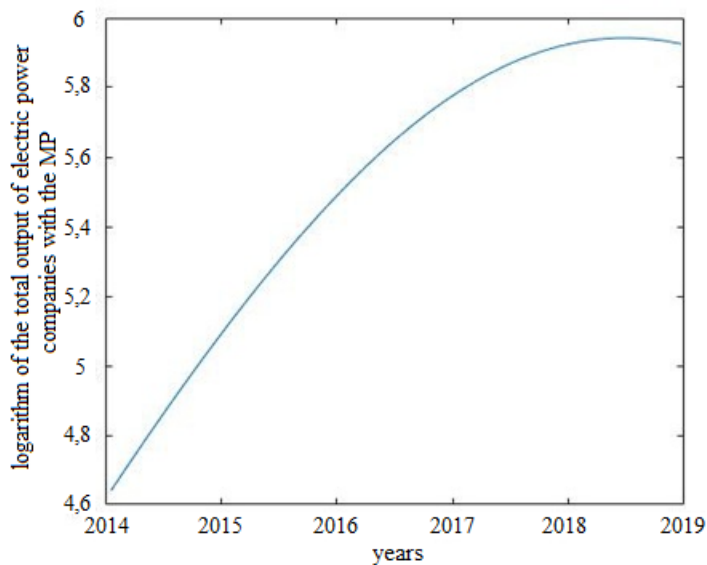

Figure 5. Integral dynamics of the economic growth of the system, represented at the figure 4 with the inclusion of the marginal price forming. **Source:** estimated by the authors [25]

Simultaneously is shown the possibility for the subtle analysis of the dynamics of the specialization and localization of agents, which will be rather important, provided the following development of centralized and distributed power information systems in Russia.

It is expedient to use developed and tested algorithms for the evaluation of the accelerated development of following significant branches, namely, economics of the knowledge.

6. References

[1]. Grachev I D 2010 *Methodology and Econophysical Tools for Economic Progress Modeling* (Moscow: CEMI) p 409

[2]. Grachev I D 2017 *Innovation economy models and techniques* vol 11, ed E Y Khrustalyov and K A Bagrinovsky (Moscow: CEMI) pp 42–47

[3]. Anikeenok O A and Eremin M V 2019 *Guidance of Self-consistent Field Method with Hartree-Fock Approximation* (Kazan: Kazan State University) p 30

[4]. Sabir A and Ibrir S 2020 Robust disturbance rejection control of grid-connected fuel cell converters with grid support ability under unbalanced faults *Energy Syst.* **11** 673–698 https://doi.org/10.1007/s12667-019-00332-4

[5]. Choudhury T R, Nayak B, De A et al 2020 A comprehensive review and feasibility study of DC–DC converters for different PV applications: ESS, future residential purpose, EV charging *Energy Syst.* **11** 641–671 https://doi.org/10.1007/s12667-019-00331-5

[6]. Voropay N I 2017 *Tenth Int. Conf. Management of Large-Scale System Development (MLSD)* (Moscow: National Research University – Higher School of Economics)

[7]. Koutovoy G P 2019 *Regional energy and energy conservation* vol 3, ed E Zholudeva et al (Moscow: System Consulting) pp 80–84

[8]. Fedorov Ya P 2019 Financial and Economic Aspects of Power: 10 Years After Liquidations of RAO UES *Russian Journal of Entrepreneurship* vol 20(1), ed O D Protsenko et al (Moscow: Creative Economy) pp 173–184 DOI: 10.18334/rp.20.1.39753

[9]. Gushchin N and Gubaidullina A 2019 *Realnoe Vremya* **21**

[10]. Edelstein-Keshet L 2005 *Mathematical Models in Biology* (Vancouver: University of British Columbia) p 586

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

[12]. Makarov A A and Veselov V F 2018 *Eleventh Int. Conf. Management of Large-Scale System Development (MLSD)* (Moscow: National Research University – Higher School of Economics)

[13]. Glaziev S Y 2016 National economy structures in the global economic development *Economics and Mathematic Methods* vol 52(2), ed V L Makarov et al (Moscow: Science) 3–29

[14]. Glaziev S Y 2016 Applied results in the theory of world economic structures *Economics and Mathematic Methods* vol 52(3), ed V L Makarov et al (Moscow: Science) 3–21

[15]. Belyaeva A V and Grebenyuk E A 2014 Building of models of the mass evaluation of real estate objects provided the spatial dependence *Control Sciences* vol 1, ed F T Aleskerov et al (Moscow: Sensidat-Plus) 45–52

[16]. Federal Act No 135 of 29 July 1998 On Concerning Valuation Activities in the Russian Federation *Russian Federation Code*

[17]. Krzysztof G et al 2000 *The European Group of Valuers' Associations* (Belgium – Gillis nv/sa) p 378

[18]. Weiss Pierre 1907 *J. Phys. Theor. Appl.* **6** 661-690 https://doi.org/10.1051/jphystap:019070060066100

[19]. Boudec J Y L et al 2007 *Fourth Int. Conf. on the Quantitative Evaluation of Systems (QEST)* (UK – Edinburgh) pp 3–18 doi: 10.1109/QEST.2007.8 https://dx.doi.org/10.1007/s11537-007-0657-8

[20]. Grachev I D and Nekrasov S A 2013 *National Interests Priorities and Security* vol 4(193), ed S F Vikulov et al (Moscow: Finance and Credit) 2–6

[21]. Stridbeck U et al 2005 Electricity Market Experience: Lessons from liberalised electricity markets *International Energy Agency* (France: Cedex) 274

[22]. Sitharthan R, Geethanjali M and Pandy TKS 2016 Adaptive protection scheme for smart microgrid with electronically coupled distributed generations *Alexandria Engineering Journal* **55(3)** 2539-2550

[23]. Fathima AH, and Palanisamy K 2014 Battery energy storage applications in wind integrated systems—a review *IEEE International Conference on Smart Electric Grid* 1-8

[24]. Prabaharan N and Palanisamy K 2015 Investigation of single-phase reduced switch count asymmetric multilevel inverter using advanced pulse width modulation technique *International Journal of Renewable Energy Research* **5(3)** 879-890.

[25]. Jerin ARA, Kaliannan P and Subramaniam U 2017 Improved fault ride through capability of DFIG based wind turbines using synchronous reference frame control based dynamic voltage restorer. *ISA transactions* **70** 465-474

[26]. Sitharthan, R, Sundarabalan CK, Devabalaji KR, Nataraj SK and Karthikeyan M 2018 Improved fault ride through capability of DFIG-wind turbines using customized dynamic voltage restorer *Sustainable cities and society* **39** 114-125

[27]. Prabaharan N and Palanisamy K 2016 A single-phase grid connected hybrid multilevel inverter for interfacing photo-voltaic system *Energy Procedia* **103** 250-255

[28]. Palanisamy K, Mishra JS, Raglend IJ and Kothari DP 2010 Instantaneous power theory based unified power quality conditioner (UPQC) *IEEE Joint International Conference on Power Electronics, Drives and Energy Systems* 1-5

[29]. Sitharthan R and Geethanjali M 2017 An adaptive Elman neural network with C-PSO learning algorithm-based pitch angle controller for DFIG based WECS Journal of Vibration and Control **23(5)** 716-730

[30]. Sitharthan R and Geethanjali M 2015 Application of the superconducting fault current limiter strategy to improve the fault ride-through capability of a doubly-fed induction generator–based wind energy conversion system *Simulation* **91(12)** 1081-1087

[31]. Sitharthan R, Karthikeyan M, Sundar DS and Rajasekaran S 2020 Adaptive hybrid intelligent MPPT controller to approximate effectual wind speed and optimal rotor speed of variable speed wind turbine *ISA transactions* **96** 479-489

[32]. Sitharthan R, Devabalaji KR and Jees A 2017 An Levenberg–Marquardt trained feed-forward back-propagation based intelligent pitch angle controller for wind generation system *Renewable Energy Focus* **22** 24-32

[33]. Sitharthan R, Sundarabalan CK, Devabalaji KR, Yuvaraj T and Mohamed Imran A 2019 Automated power management strategy for wind power generation system using pitch angle controller *Measurement and Control* **52(3-4)** 169-182

[34]. Sundar DS, Umamaheswari C, Sridarshini T, Karthikeyan M, Sitharthan R, Raja AS and Carrasco MF 2019 Compact four-port circulator based on 2D photonic crystals with a 90° rotation of the light wave for photonic integrated circuits applications *Laser Physics* **29(6)** 066201

[35]. Sitharthan R, Parthasarathy T, Sheeba Rani S and Ramya KC 2019. An improved radial basis function neural network control strategy-based maximum power point tracking controller for wind power generation system *Transactions of the Institute of Measurement and Control* **41(11)** 3158-3170