The modeling of the efficiency in the new generation manufacturing-distributive systems based on the cognitive production factors

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Abstract. The paper envisages the analysis of the new generation manufacturing-distributive systems. The particular attention is paid to the production function as the analytic instrument allowed evaluating the interrelation between economic results of an enterprise and production factors, which includes the cognitive production factors as well. The rationale for the enlargement of the traditional production functions by means of the transfer from the multiplicative to the logistic dependence has been analyzing. The results of production function modelling on the base of the logistic dependence have been depicted on the open data of a high tech enterprise from 2009 till 2018. The results of production function modelling have shown that the usage of logistic dependence has allowed tracing more precise the transition of production factors to the other path dependency. The inclusion of the cognitive production factors has allowed evaluating their contribution to the economic results of a high-tech enterprise. This work is still in progress and the presented results are preliminary and would be added and specified by the additional research.

1. Introduction
The existing challenges of the modern industrial manufacturing deal with the provision of the economic efficiency of mass production in transition to the agile customizable manufacturing-distributive systems. That can be called the systems of the new generation [1]. The relevance of its development is explained by the vast expansion of IT-technologies that determine the economic efficiency level of these systems as economic entities. In particular it is distinctly traced by the activity of high-technology enterprises that can be considered as the prototype of such systems.

High-tech enterprises are characterized by the increasing division of “material” and “non-material (intellectual)” manufacturing components; the establishment of intellectual part as a standalone product; the reinforcement of the globalization in the process of a new product [2]. Attended in these circumstances technical and economic barriers, imbalances in innovation-driven development connect with the inefficiency of existing production factors and the appearance of new ones, among them cognitive production factors as well. Under the cognitive production factors there is an amount of knowledge, capabilities that provide the gain in productivity while manufacturing product commercially successful [3].

Traditional approaches to the evaluation of the production factors efficiency from one side allow taking into consideration all effects in one indicator, from the other side assumptions that lay in the
base of economic and mathematical models are often open to the fair criticism, as they don’t consider the incremental and cyclic dynamics of the manufacturing-distributive systems of the new generation [4].

The processes of reciprocal transitions in qualitative and quantitative changes in the development of complex dynamic systems are modelled by the logistic curves [5]. Due to the interchange of evolutionary and revolutionary processes their dynamics presents the incremental and cyclic process. Thus there is the necessity of the modified production function elaboration and the modelling of the efficiency of the new generation manufacturing-distributive systems on the base of open data of a high-tech enterprise.

The paper has the following structure: part 1 presents the review of main approaches to the usage of the production function and depicts the peculiar characteristics of logistic curve; it also describes the notion of cognitive production factors and its typology; part 3 deals with the description of high-tech enterprises and peculiarities of Russian high-tech sector; part 4 presents the modelling procedure on the open data; part 5 finishes the paper with the results and conclusion.

2. Theoretical Background

2.1. Main approaches in the production function modelling

In the economic modelling there are two basic approaches in the evaluation of manufacturing efficiency: the total factor productivity (TFP), so called R. Solow’s residual and the production possibility frontier (PPF) [6-9].

In Solow’s approach it is assumed that the technological progress is exogenous and is determined as the part of output growth, not explained by the accumulation of production factors [4, 9]. This component, Solow’s residual is the estimation of the technology progress. In Solow’s approach the basic assumptions are following: the constant returns to scale in economy, the functioning of enterprises in terms of the perfect competition, the functioning of economies on the frontier of manufacturing capabilities. These assumptions are wide open to criticism [10, 11]. In real conditions one can register not only constant but increasing returns to scale. This issue has been considered in framework of so called PPF’s approach that presents the non-parametric envelope curves, based on linear programming methods and the stochastic frontier of manufacturing capabilities intending the usage of panel data.

In the method of non-parametric envelope curves the efficiency level is measured by the degree of the potential implementation, i.e. the remoteness of a high-tech enterprise from its frontier of manufacturing capabilities. This method constitutes in the evaluation of the output deviation functions and also in the search of the maximum possible output. The main limitation of this approach is the deterministic character. This approach doesn’t assume the “noise” in data; it is considered that all combinations “factors-output” presented in the observation can be achieved.

The approach of PPF described in [4, 9] allows taking into consideration the presence of random effects including measurement errors, that influence the deviation from the frontier. The influence of these random effects is taken into account by the decomposition of model residuals into the “noise” and “inefficiency” component, so called the extent of output deviation from its frontier level, which could be achieved in the given volume of production factors. The method of the stochastic frontier supposes that enterprises act not on the frontier but inside their manufacturing capabilities. This method allows reflecting two aspects: the shift of manufacturing capabilities’ frontier (scientific and technical progress) and the movement of an manufacturing-distributive system along this frontier (enterprise’s efficiency dynamics). The inefficiency arises when an manufacturing-distributive system is inside of manufacturing capabilities’ frontier and the output can be increased with the existing technologies and production factors. The farer the high-tech manufacturing-distributive system is from manufacturing capabilities’ frontier the higher its inefficiency.

The conducted review has shown that these approaches have been used for evaluating aggregative manufacturing-distributive systems’ efficiency on the country level. However in these approaches
there isn’t been taken into account the incremental and cyclic dynamics of the scientific progress on the level of a high-tech manufacturing-distributive system. Meanwhile mainly high-tech manufacturing-distributive systems are drivers for any national economy.

2.2. **The peculiarities of logistic curves**

The usage of the logistic curve one could find in works of many researches [5, 12, 13]. The logistic curve possesses the following peculiarities:

- The growth of investigated indicator with the growth of the argument;
- Changes in growth rate (increase and decrement);
- The growth ceiling.

The complexity of taking investing decisions deals with the fact that the choice of this or that set of production factors will determine the effect of its implementation – the ratio that determine the lifecycle phase of cognitive production factors in the moment of investment. As in a every time a high-tech manufacturing-distributive system has a limited set of cognitive production factors that could be supported by investment resources, thus the investment process is characterized by the discrete values of results putting at odds short-term and long-term investment goals. One of the problems is the forecast of the growth ceiling some of competitive cognitive production factors, designed for solving the same economic task.

The research of cognitive production factors asks the question whether the law of decreasing returns is correct. In short-term this law is senseless, as the increase of cognitive production factors supposes the modernization of manufacturing and the increase of employees’ qualification, i.e. the changes of all production factors. Alongside with this the law of decreasing returns relate to the long-term period is trustful at the definite stages of the life cycle.

Taking into account that the second order derivative of the generalized logistic curve changes sign several times, the increasing and decreasing returns also change each other by turns [5,12,13]. This circumstance coincides with the obsolescence of production factors and cognitive ones as well. The usage of the modified production function on the base of the logistic curve allows evaluating the efficiency of high-tech manufacturing-distributive systems and also forecast the tipping points in the increasing and decreasing returns.

2.3. **Cognitive production factors**

In terms of modern economy the innovations consider as one of main sources for economic growth. Dynamic innovation development of high-tech manufacturing-distributive systems leads to the significant changes in national economy structure and determine the priorities of scientific and technological development of a country [2, 14-17].

The Russian high-tech manufacturing-distributive systems are the object of research for many Russian scientific schools [2, 15, 17, 18]. High-tech manufacturing-distributive systems are researched and analyzed from the perspective of its contribution to gross domestic product; amount of employees in high-technology sector; a share of R&D expenses in total expenses of a high-technology manufacturing-distributive system; a share of scientific extensive product in export flows.

However, namely the micro level of high-technology sector, the economy of a separate manufacturing-distributive system determines the development of high-technology sector as a whole. Its insufficient efficiency is due to the imbalance of innovation development, imbalance in productivity, imbalance in the usage of production factors.

According to [12] one additional percent of labour expenses increases output three time more than one additional present of capital expenses that impose the necessity to use inner resources in the achievement of strategic goals of a high-tech manufacturing-distributive systems.

High-tech manufacturing-distributive systems facing strategic tasks increase the relevance and practical meaning of production factors research, the nature of its impact to the results of a high-tech manufacturing-distributive system as an economic entity. The shaping factors are knowledge, know-how, R&D, i.e. intellectual component of manufacturing capabilities.
The premises of production factor theory are that the cost-effectiveness balance determines the strategic position of a manufacturing-distributive system in the market space. Conceptual issues of the modern production factors theory are following:

- Economic sustainability of a high-tech manufacturing-distributive system determines by the cost-effective balance of existing factors and their effective management;
- Competitive advantages depend on the availability of strategic resources;
- Effective management of existing production factors is provided by the organization possibilities of a high-tech manufacturing-distributive system.

The question has been arisen, what peculiarities should have production factors that the innovation-driven development would run effectively and intensively? The cyber economy has changed dramatically the traditional production factors. If in industrial economy the shaping factors were the labour and the capital, in the post-industrial economy the shaping factors are high technologies and high rates of technological renewal. As the consequence the economic efficiency depends on the quality of human capital and a developed IT-infrastructure.

The amount of specialized knowledge, skills, and competences to transfer them in a competitive product allows singling out new type of production factors – cognitive production factors.

In scientific literature [19-24] the production factors are usually classified as basic, key, leading, strategic, shaping, etc. in this paper we use the typology of cognitive production factors suggested in [1].

The main criterion of distinguishing is the dichotomy “material/non-material” and “active/intentional”. These two measures form four quadrants of the indexer, each from which coincides with the definite type of cognitive production factors (fig.1).

![Figure 1. Types of cognitive production factors.](image)

To material-active one can relate those cognitive production factors that have a material form and use in the economic activity of a high-tech manufacturing-distributive system, such as local computer networks, flexible manufacturing systems, robots, automated storage systems, planning systems, design systems, electronic document flow systems, systems of technical vision, etc.

To non-material-active one can relate intellectual property issues: know-how, licenses, data base, relations with clients, suppliers, etc.

To material-intentional one can relate potential advanced technologies, such as augmented reality technologies, artificial intelligence technologies, fog computing, deep learning, etc.

To non-material intentional one can relate experience, education level of employees, digital literacy, capacities for analysis, reflection, self-regulation, communicative skills, etc.

This list of cognitive production factors is not comprehensive and could be added and enlarged.

3. Characteristics of high-tech manufacturing-distributive systems

According to the Strategy of Economic Development in the Russian Federation (www.economy.gov.ru) [25], innovative economy is of high priority for Russia’s long-term strategic development. In this regard, high-tech manufacturing-distributive systems play an important role. Below we will present a brief overview of the Russian high-tech sector based on existing studies [26, 27] and official documents [28-30].
The share of the Russian high-tech sector in world trade accounts for about 1.3% [31,32]. The most developed industries are defense, space, and aviation, which can be explained by the rich industrial heritage and a significant scientific potential. The share of the high-tech sector in the gross domestic product is quite large and constitutes 21% (see fig. 2) [30].

![Figure 2. The share of high-tech products in Russia’s GDP.](image)

The structure of Russian high-tech export is rather heterogeneous. The largest share in the output of the high-tech sector is composed of commercial products of the aviation and space industries, as well as the products of defense industry. The proportion of products of the electronic complex is 14%, the nuclear industry - 13.6%. Thus, the export of Russian high-tech manufacturing-distributive systems is concentrated within the narrow specialized areas of high-tech products, while the competitiveness of these manufacturing-distributive systems is several times lower in commodity groups designed for a mass end user.

Following [33, 34], the Russian high-tech sector is structured by the defence industry (28.6%), the space and avia industries (21.2%), the information and communication industry (18.9%), the medical equipment industry (14.3%), etc (see fig. 3).

![Figure 3. Structure of the Russian high-tech sector.](image)

The distinctive characteristic of the Russian high-tech sector is the numerous industrial chains that are actively developing at the moment. At the same time, there has appeared a large number of ideas.
supported by different kinds of multidisciplinary R&D groups, although their significant efforts do not always lead to the commercialization of these ideas. However, in comparison with the manufacturing-distributive systems of medium technological industries, high-tech manufacturing-distributive systems lose in terms of the share of innovative products in the total output. This happens due to significant investment and innovation lags in the high-tech sector and the low performance of the Russian high-tech sector.

In the Russian Federation, the key areas of scientific and technical progress are reflected in the Priority Industries List [33] for the development of science and technology that generally comply with the world scientific and technological priorities: information and telecommunication systems; life sciences; the industry of nanosystems; transport and space systems; resource saving technologies; energy efficiency, energy saving nuclear energy. The development of these areas is aimed at shaping the non-defense high tech sector in the Russian economy.

Summing up, we could formulate the following characteristics of the high-tech sector in Russia:
- The high-tech sector influences the general economic development in Russia;
- The defence, aviation, and space industries give the largest input in the Russian high-tech export;
- Most high-tech manufacturing-distributive systems are still in state ownership as any efforts in attracting private investments have been hindered by the nature of the high-tech sector;
- Multidisciplinary R&D groups generate a great number of ideas, although commercialization does not always take place due to considerable innovation lags.

4. An Efficiency model of a high-tech manufacturing-distributive system on the base of the modified logistic curve

Taking into account that the main goal of a high-tech manufacturing-distributive system is the output of innovation product its performance function is the profit maximization of its output. The factors of the production function are capital, labour and cognitive production factors. The dependence is based on the logistic curve; the level of saturation is determined by the development level of production factors. The growth of factors is determined by the investments with the distributed lag. The suggested model is the description of the replenishment cycle, taking into account the incremental and cyclic dynamics of a high-tech manufacturing-distributive system:

\[ Y_t = S (K_t, L_t, CPF_t) \] (1)

\[ S (K_t, L_t, CPF_t) = K e^{-a(K_t, L_t, CPF_t)}/(1+K e^{-a(K_t, L_t, CPF_t)}) \] (2)

Considering the fact that the cognitive production factors are qualitative notion there is a necessity to make them quantitative. Table 1 presents their correlation with the quantitative economic parameters.

**Table 1.** The correlation of the production factors and the economic parameters.

| Production factor         | Economic parameter                                                                 | Source of information       |
|--------------------------|-----------------------------------------------------------------------------------|-----------------------------|
| Capital                  | Own long-term capital, own circulating capital                                     | Balance sheet, form 1       |
| Labour                   | Labour expenses with social tax remission                                         | Balance sheet, Form 4       |
| Cognitive production     | Residual value of basic assets (MA), a share of property funds in R&D (MI); intellectual property value (IA); turnover rate of R&D personnel (II) | Balance sheet, Form 1, Form 2 |
| factors                  |                                                                                   |                             |

In order to check the correctness of the logistic dependence between production factors and the results of a high-tech manufacturing-distributive system we have taken open data of one high-tech enterprise [35] for a period from 2009 till 2018. These prepared data for modelling are presented in table 2.
Table 2. Open data of a high-tech manufacturing-distributive system

| Year | Capital | Labour | Cognitive production factors |
|------|---------|--------|-----------------------------|
| 2009 | 77.8    | 2      | 89.84                       |
| 2010 | 66.5    | 2.4    | 83.8                        |
| 2011 | 71.3    | 5.6    | 84.43                       |
| 2012 | 72.77   | 15.42  | 85.71                       |
| 2013 | 68.96   | 16.74  | 83.88                       |
| 2014 | 73.84   | 16.56  | 86.27                       |
| 2015 | 86.97   | 14.53  | 93.91                       |
| 2016 | 106.23  | 16.13  | 106.5                       |
| 2017 | 104.3   | 17.6   | 113.81                      |
| 2018 | 126.1   | 19.15  | 129.65                      |

4.1. Results of modeling

In the process of modelling we have singled out two stages: the logistic primary curve without the time period shift and with the time period shift and the logistic secondary curve without the time period shift and with the time period shift. The results of the first phase are presented on fig.4,5. The results of the second phase are described on fig.6,7.

Figure 4. The logistic primary curve without the time period shift

Figure 5. The logistic primary curve with the time period shift

The coefficients of the first phase are presented in table 3.
Table 3. Coefficients of the modelled production factors

|                | Primary curve without time period shift | Primary curve with time period shift |
|----------------|----------------------------------------|-------------------------------------|
| Capital        | K = 15.719                             | K = 2.138                           |
|                | a = 0.154                               | a = 0.005                           |
| Labour         | K = 5.113                               | K = 39.456                          |
|                | a = 0.317                               | a = 2.332                           |
| CPF            | K = 16.643                              | K = 1.018                           |
|                | a = 0.112                               | a = 0.005                           |

Figure 6. The logistic second-degree curve without the time period shift

Figure 7. The logistic second-degree curve with the time period shift

The coefficients of the second phase is presented in table 4.

Table 4. Coefficients of the modelled production factors

|                | Second-degree curve without time period shift | Second-degree curve with time period shift |
|----------------|-----------------------------------------------|-------------------------------------------|
| Capital        | K = 1.052                                      | K = 0.879                                 |
|                | a = 0.008                                      | a = 0.106                                 |
| Labour         | K = 22.57                                      | K = 2.607                                 |
|                | a = 0.412                                      | a = 0.025                                 |
| CPF            | K = 597.019                                    | K = 1.146                                 |
|                | a = 0.14                                       | a = 0.185                                 |

The results of modeling have shown that the change from the multiplicative dependence to the logistic dependence have the confirmation especially with the labor factor. Concerning the cognitive production factors and the capital the logistic curve is not so evident. Perhaps the data series are not
too long and we need to enlarge it. Another possible explanation of weak statistical meanings is the direct correlation between theoretical notions of production factors and real economic indicators. As this work is in progress we consider the given results rather meaningful and the future work will be devoted to find the indirect parameters of cognitive production factors’ influence.

5. Conclusion
In the literature of the production processes the dominant idea is standard multiplicative production functions. However they don’t take into account in the present time the manufacturing terms have changed dramatically: Industry 4.0, expansion of IT, etc. In the present paper an attempt has been undertaken to consider cyber and intelligent technologies by means of introduction a new notion – cognitive production factors. The review of the traditional approaches for the efficiency modelling has shown that they don’t allow taking into consideration the technologic ceiling of existing production factors and the necessity to transfer to other technologic base. In the present paper the new approach has been elaborated and production function has been modified on the base of the logistic curve. The modelling of the modified production function on the open data has allowed evaluating the statistical meaning of the suggested idea. Though the modelling results are quite modest from the point of statistics, we consider them successful. The present paper presents a part of a larger scientific work and enlarged by other aspects and results. In the end it is necessary to mention about the limitation of this paper. Certainly the data series is not too large and probably we should find other quantitative equivalents of such qualitative notion as cognitive production factors.

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