Multicriteria models for structural analysis of human capital reproduction strategies of knowledge-intensive enterprises in the context of digitalization

Igor Kartsan1,2*, Aleksandr Zhukov3,4, and Sergey Pronichkin3,5,6

1 Marine Hydrophysical Institute, Russian Academy of Sciences, 2, Kapitanskaya str., Sevastopol, 299011, Russia
2 Reshetnev Siberian State University of Science and Technology, 31, Krasnoiarskii Rabochii Prospekt, Krasnoyarsk, 660037, Russia
3 The Federal Center of Expertize and Analyzis, 33, p. 4, Talalikhina str., Moscow, 109316, Russia
4 Institute of Astronomy of the Russian Academy of Sciences, 48, Pyatnitskaya str., Moscow, 119017, Russia
5 Federal Research Center “Computer Science and Control” of Russian Academy of Sciences, 40, Vavilov Street, Moscow, 119333, Russia
6 Central Economics and Mathematics Institute of Russian Academy of Sciences, 47, Nakhimovsky Prospekt, Moscow, 117418, Russia

Abstract. Improving the human capital reproduction organization, which is a key guideline on the path of innovative development of the digital economy, requires fundamentally new approaches to finding sources of investment in the intangible digital assets formation. It is proposed to calculate the growth rate of the value of intangible digital assets of a knowledge-intensive enterprise on the basis of a reinvestment mechanism according to many criteria. Multi-criteria models have been developed to reflect the potential production capabilities of knowledge-intensive enterprises, their ability to increase investment potential through the introduction of various strategies for the human capital reproduction.

1 Introduction

Despite positive changes in the implementation of the concept of the digital economy and new priorities of scientific and technological policy, which create the basis for the socio-economic development of the regions. The material and technical base of leading types of economic activity, in particular those related to the IT sector, remains underdeveloped. This is largely due to the gap between the required and available level of investment support for the human capital reproduction processes.

The papers [1, 2] highlight the qualitative and quantitative characteristics of the norm and structure of savings, mechanisms for converting them into investments, the sectoral structure of human capital, individual institutional and investment-innovative factors of economic

* Corresponding author: kartsan2003@mail.ru

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growth in the context of digitalization. The importance of digital innovations is largely due
to the accelerated pace of development of globalization processes, and therefore competition,
in digital markets for goods and services [3, 4].

Fundamental changes in the operating conditions of knowledge-intensive enterprises,
which have occurred recently and will continue to intensify as a result of global
transformation, make inevitable changes in their activities, in particular, in the direction of
bringing the general management system and organization of production to virtual offices [5,
6]. In such conditions, the need to develop predictive models of the dynamics of the value of
human capital according to many criteria, primarily at the micro level, becomes urgent.

2 Materials and methods

The level of renewal of human capital of knowledge-intensive enterprises characterizes the
potential of the economy, and the dynamics of its value reflects general trends in socio-
economic development and the ability of capital for expanded reproduction. To reach the
technical level of industrialized countries, developing countries need to accelerate the
renewal of human capital [7, 8]. In addition, there is a significant predominance of the
renewal rate over the capital retirement rate.

In general, the investment process in developing countries is extensive in nature [9, 10].
The growth rate of investment in human capital tendentiously exceeds the growth rate of the
initial cost of this capital. The consequence of ineffective capital investments is the
accumulation of obsolete intangible assets in enterprises, primarily in the IT sector, which in
turn increases the cost of servicing human capital, reducing labor productivity indicators. As
a result, this creates emergency situations, reduces the overall level of production and causes
technical and technological backwardness, primarily in the knowledge-intensive sector of the
national economy. Under such circumstances, the functioning of most types of economic
activity in the context of digitalization will be accompanied by a constant increase in costs.

The durability of human capital allows it to be accumulated, but it can only be reproduced
for a certain period, the duration and effectiveness of which depend primarily on the results
of activities at the micro level, since it is the own funds of knowledge-intensive enterprises
in developing countries that are the main source of investment in human capital.

Thus, in modern conditions, one of the most realistic forms of financial support for the
development of the IT sector of the national economy, which will create a stable basis for the
expanded reproduction of human capital of knowledge-intensive enterprises in the context of
digitalization, is reinvestment.

Reinvestment can take many forms. With the development of information and
communication technologies (ICT), new opportunities are opening up for improving the
quality of human capital [11, 12]. The traditionally narrow consideration of digital
technologies in the technical and technological aspect must be overcome as providing fast,
accurate, complete, reliable delivery of information, its accumulation, storage, conversion of
various forms of representation, regardless of the nature and content of the information, as
well as the ability to consume it. Information and communication technologies have another
important aspect associated with their ability to take into account the characteristics of socio-
cultural information, its specific types and forms, which effectively form not just any, but
only the types and forms of human competencies adequate to them. Such information and
communication technologies, in contrast to traditional ICT, are called high innovative
technologies [13, 14].

Innovations that influence the socio-economic development of the country are divided
into “strong” and “weak” [15]. And only “strong innovations” are of decisive importance in
the evolution of human capital, and, taking root, they turn into a tradition, therefore they are
called “strong” [16, 17]. Innovations can be interpreted as newly created (applied) and/or
improved competitive technologies, products or services, as well as organizational and technical solutions of a production, administrative, commercial or other nature, significantly increasing the quality, efficiency and effectiveness of knowledge-intensive enterprises [18, 19]. At the same time, the main elements of innovation are its carrier (a creative person), who has a certain innovative idea (the core of innovation) and conducts an innovative experiment (the source of innovation); consumer of innovation; as well as knowledge-intensive enterprises that ensure the introduction of innovations.

3 Results

To determine the impact of various reinvestment strategies on the dynamics of the initial cost of human capital of a knowledge-intensive enterprise in period \( p \), we introduce the target function of added value from digitalization according to many criteria:

\[
D_p = f(G_p, S_p, A_{p-1}, N_p)
\]

where \( D_p \) is an indicator of added value from digitalization, \( G_p \) is revenue from the sale of digital products and services in period \( p \), \( S_p \) is personnel costs in period \( p \), \( A_{p-1} \) is amortization of intangible digital assets for the previous period, \( N_p \) is costs for research and development, including patenting intangible digital assets.

To determine the optimal strategy \( v \) for the reproduction of human capital of knowledge-intensive enterprises from the set of feasible options \( \Omega \), sequential optimization is carried out according to the following scheme:

\[
V_{pG} = \{v: \arg \max_{v \in \Omega} G_p - \Delta_G\}
\]

\[
V_{pS} = \{v: \arg \min_{v \in V_{pG}} S_p - \Delta_S\}
\]

\[
V_{pA} = \{v: \arg \min_{v \in V_{pS}} A_{p-1} - \Delta_A\}
\]

\[
V_{pN} = \{v: \arg \min_{v \in V_{pA}} N_p - \Delta_N\}
\]

where \( \Delta_i \) are the values of quasi-optimality of criteria \( i = \{G_p, S_p, A_{p-1}, N_p\} \) in period \( p \), selected by the decision maker.

We consider the level of growth of added value from digitalization to be borderline, which ensures that a knowledge-intensive enterprise remains on the brink of break-even. The level of production of value created by a knowledge-intensive enterprise can be determined using the production function:

\[
G_p = l_p A_p
\]

where \( l_p \) is capital productivity, characterizing the efficiency of using the human capital of a knowledge-intensive enterprise. Since the capital productivity indicator is not stable over time, its value in period \( p \) can be determined as follows:

\[
l_p = l_0(1 + \alpha_p)^p
\]

where \( l_0 \) is the capital productivity indicator at the beginning of the calculation period, \( \alpha_p \) is the growth rate of capital productivity for the period \( p \).

In conditions when the production potential of a knowledge-intensive enterprise is not dynamic enough, that is, the expansion of activities occurs more slowly than is necessary in the conditions of digitalization, the enterprise loses development prospects. Conversely, if an
enterprise increases production at a rate significantly exceeding \( \Delta D^* \), then it has the opportunity to implement a policy of further expanding its activities and strengthening its competitive position in the market of digital products and services.

The critical value-added growth index should be minimal. This will provide the company with the opportunity to remain profitable even with a decrease in production during crisis periods associated with a drop in demand for its products. A knowledge-intensive enterprise, in order to reduce the critical value of added value indicators according to many criteria, needs to increase the capital productivity of human capital at an accelerated pace, as well as reduce the share of labor costs and other operating expenses in added value. Knowledge-intensive production creates the prerequisites for the proper renewal of human capital from the standpoint of mobilization, planning and concentration of resources, as well as flexible maneuvering of them. In conditions of global instability, the lack of production capacity becomes the main factor limiting the further increase in production.

At the same time, small businesses, as a result of integration with large knowledge-intensive enterprises, can significantly contribute to the stable implementation of an effective policy of intensive renewal of human capital [20, 21]. High-tech enterprises can use scientific equipment from various companies and manufacturers by purchasing, renting or leasing it. If the available capacities can only create technologically backward, non-competitive products, the demand for which is invariably falling, then whatever the balance sheet valuation of these capacities, their real replacement cost approaches zero. Thus, the production and operation of technologically outdated, unpromising equipment will cease. Therefore, it is important to assess which part of the fixed production assets actually corresponds to the latest technological level, which can only be done by the dynamics of the investment potential actually created by them on the basis of knowledge-intensive solutions. Any other approach gives purely formal results that are unacceptable for a clear reflection of the current state of the human capital of a knowledge-intensive enterprise.

In general, the dynamics of the initial value of intangible digital assets of a knowledge-intensive enterprise at the end of period \( p \) can be described by the following equation:

\[
A_p = w_{p-1}A_{p-1} + N_p
\]  

(5)

where \( w_{p-1} \) is the accelerated depreciation rate of intangible digital assets, \( N_p \) is investment in human capital in period \( p \).

The purpose of depreciation is to maintain intangible digital assets at the same level without changing their value, which modifies equation (5). We will also assume that depreciation is not aimed at consumption, but is completely reinvested in high-tech production. If we take into account the fact that investments in human capital are made by the enterprise from net profit, according to the chosen strategy for the reproduction of human capital, then model (5) takes on the following form:

\[
A_p = A_{p-1} + \gamma_p D_p
\]  

(6)

where \( \gamma_p \) is a coefficient that determines the share of net profit of a knowledge-intensive enterprise reinvested in human capital; \( \gamma_p < 1 \) provided that the enterprise uses only its own financial resources for investment, \( \gamma_p > 1 \) otherwise.

The potential production capabilities of a knowledge-intensive enterprise to increase investment potential, taking into account various resource limitations of the strategy for the reproduction of human capital, can be calculated using the following ratio:

\[
\frac{A_p}{A_{p-1}} = \left( \frac{1-\gamma_p w_{p-1} \beta_p}{1-\gamma_p \frac{1}{1+\alpha_p} \beta_p} \right)^p
\]  

(7)
The rate of growth in the value of human capital of a knowledge-intensive enterprise directly depends on the value of capital productivity and its growth, the accelerated depreciation coefficient of intangible digital assets, as well as the coefficient $\beta_p$ of labor costs.

The growth in the value of intangible digital assets of knowledge-intensive enterprises due to the action of the reinvestment mechanism increases only if the efficiency of their use increases and the share of labor costs and other operating expenses in added value decreases.

Subject to a negative increase in capital productivity, further reinvestments will not lead to an increase in the value of intangible digital assets. This is explained by the interdependence between indicators of capital productivity and value added. The decrease in capital productivity is a direct consequence of a decrease in added value, and ultimately, the volume of reinvestment.

The growth of intangible digital assets of a knowledge-intensive enterprise can coincide with the growth rate of the added value created by it, provided that the capital productivity indicator remains unchanged. The increase in the value of human capital limits a critically large share of costs in added value at a low level of capital productivity, which, on the basis of reinvestment, does not allow us to reflect in detail all aspects of this process, taking into account several objective reasons:
- profits reinvested in knowledge-intensive production are not always transformed into intangible digital assets within one period, that is, the final materialization of human capital occurs only within a few years, in particular when new digital solutions are introduced;
- introduction into strategic analysis of the investment lag necessary for the development of investment funds for research and development by a knowledge-intensive enterprise.

Reinvestment models in the digital economy, which determine the success of knowledge-intensive enterprises, should be aimed at integrating scientific and scientific-technical activities into the innovative research spaces of the digital economy. This gives rise to fundamental tasks of scientific substantiation and practical modernization of target, content, technological, and organizational aspects of the formation of human capital.

In knowledge-intensive enterprises, there is a translation of experience (information), which occurs not directly, but through preliminary transformation (selection, systematization, simplification, expression, presentation, etc.) of latent information, the direct perception of which is difficult, into so-called accessible information for development at the proper level of employee development. Such information adequately (isomorphically) reflects the accumulated innovative experience. The content of innovative experience is recorded in methodological developments, visual diagrams and models.

In forecasting the development of human capital of knowledge-intensive enterprises, developing an improvement strategy, and implementing appropriate organizational and managerial actions, one should clearly understand the nature of the reproduction of human capital as an information and communication system, the factors and conditions that entail its natural emergence as an orderly and ordering phenomenon. This allows us to coordinate self-organization, organization and management in the national innovation system, to prevent it from entering a risky, unbalanced, crisis, catastrophic state. The expedient, effective information-ordering action of the reproduction of human capital leads to an increase in the level of organization of innovative enterprises, and then to their better functionality in achieving the strategic goals of sustainable development.

4 Discussion

Multi-criteria descriptive decision-making models have been developed for choosing a strategy for the development of human capital of a knowledge-intensive enterprise, taking into account the operation of the reinvestment mechanism. The presented models, despite the
presence of certain limitations, make it possible to quantitatively describe not only the process of generating the net profit of a knowledge-intensive enterprise, but also the scheme for using this profit, i.e., it reflects a closed cycle of expanded reproduction at the micro level.

The multicriteria selection of the optimal strategy takes into account the presence of systemic dependencies between indicators of growth in the value of human capital and the efficiency of its use (increase in capital productivity), on the one hand, and the share of operating expenses in the added value created by a knowledge-intensive enterprise, on the other.

Thus, an accelerated increase in the level of capital productivity with a simultaneous reduction and optimization of the structure of operating expenses at the micro level is an effective way to increase the profit of a knowledge-intensive enterprise, which, in turn, is almost the only source of capital investment in the context of a sharp reduction in foreign investment. Increasing reinvestment will revive the investment process towards updating the human capital of the IT sector of the economy based on increasing the efficiency of its functioning.

5 Conclusion

Prospects for further research are related to minimizing the number of restrictions imposed on the developed models and are taken into account when calculating the rate of reproduction of human capital of knowledge-intensive enterprises in the context of digitalization. And this, in turn, involves modification of the developed multi-criteria models, in particular, in the following main aspects: clarification of the process diagram for generating the net profit of a knowledge-intensive enterprise; formalization of sustainable cycles for updating intangible digital assets, subject to the systematic involvement of the results of fundamental research; research into the impact of other operating costs on growth indices of intangible digital assets.

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