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Institutional Spiral of the Generation of Hi-Tech Knowledge

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Abstract: An institutional spiral of high-tech knowledge generation is generated, the implementation of which has the capability of reducing the level of uncertainty throughout the entire product life cycle, and, consequently, to reduce lead times and improve the quality of all work performed. An original model of the resource potential of the generation of knowledge as a set of resources and capabilities of enterprises in the implementation of intellectual activity, detailing complementary techniques for improving the efficiency of the knowledge-generation process for high-tech enterprises, is applied. Improving the efficiency of the generation of knowledge is achieved by changing one of the types of resources (labour, material, financial, information) at particular stages of the product life cycle. The actual proportion of allocation of resources at every stage of the product life cycle in the production of large enterprises in the high-tech sector is determined based on empirical research. A comparison of the theoretical and actual resource potential of knowledge generation allows a direction for the optimisation of resource use in the economy to be defined; effective resource management ensures the efficient development and manufacture of new products.

Keywords: hi-tech knowledge, resource potential, institutional spiral, knowledge management, innovation, resources

1. Introduction

Authors distinguish the three main approaches to researching the innovative behavior of firms in the world's scientific economic literature. The first approach is developed in the framework of the neoclassical economic paradigm and primarily addresses research objectives already posed by Schumpeter, namely: "What market structures maximise innovation?" and "Does the technological breakthrough promote competition?" (Schumpeter, 1947). Research following this approach is dedicated to finding the relationship between the structure of the market and the value of R&D G. Loury (Loury, 1979), T. Lee and L. Wilde (Lee&Wilde, 1980), R. Sah and J. Stiglitz (Sah&Stiglitz, 1987), V. Delbono and V. Denicolo (Delbono&Denicolo, 1991), J. García-Manjón and M. Romero-Merino (García-Manjón&Romero-Merino, 2012), etc.; substantiating the factors that promote or hinder the network interactions of firms in the implementation of R&D P. Dasgupta and E. Maskin (Dasgupta&Maskin, 1987), E. Harrison and H. Koski (Harrison&Koski, 2009), L. Dahlander and D. Gann (Dahlander&Gann, 2010), M. Ferrary (Ferrary, 2011), etc.; and identifying incentives for the generation of knowledge for already functioning and newly established firms K. Arrow (Arrow, 1962), J. Reinganum (Reinganum, 1983), D. Teece (Teece, 2010), G. Festel (Festel, 2014) et al.

The object of study of the second approach, which is based on the principles of the evolutionary paradigm, is the innovation life cycle and the individual stages of the innovation process. The pioneering work, which drew attention to the problem of cumulativeness in the innovation process, was reported in the scientific paper by S. Skotchmer (Skotchmer, 1991). This approach was subsequently developed by such scholars as V. Denicolo (Denicolo, 2000), T. O'Donoghue (O'Donoghue, 1998), R. Hunt (Hunt, 2004) et al.

The third research approach into the innovative behaviour of firms takes the form of various classifications of knowledge generation strategies. Several typologies of knowledge management strategies are discussed in the literature. The classification of knowledge management strategies in terms of the systematisation of their attributes includes own or borrowed knowledge R. Grant (Grant, 1996); the extent of changes to the organisation of knowledge J. March (March, 1991); the speed of implementation and dissemination of new knowledge in the organisation P. Bierly and A. Chakrabarti (Bierly&A. Chakrabarti, 1996); the breadth of the knowledge base G. Hamel&C. Prahaland (Hamel&Prahaland, 1994).

At the same time, analysis of current economic theories shows there to be insufficient institutional research into resources used to support knowledge generation processes.

The purpose of this research is to develop methods of creating high-tech knowledge based on the original model of the resource potential of knowledge generation.

2. Methods for assessing knowledge generation

Based on the seven stages of the product life cycle, as well as the existing traditional four types of resources, authors develop a method comprising the following elements:

- determination of the labour resource potential of knowledge generation;
- determination of the financial resource potential of knowledge generation;
- determination of the material resource potential of knowledge generation;
- determination of the information resource potential of knowledge generation;
- determination of the resource potential of knowledge generation to the nth stage.

Let us consider the above elements in more detail.

Method for the determination of the labour resource potential of knowledge generation.

The concept of enterprise labour resources implies the integration of all individuals who are in an employment relationship with the enterprise as a legal entity governed by an employment contract. The main characteristics of this type of resources are their structure and numerical strength.

During the transition to a knowledge-based economy of high-tech enterprises, the core of quality labour resources is aimed at achieving scientific results in the area of new technologies.

The specifics of the high-tech enterprise labour force are determined by the complex nature of labour and means for its motivation, the creation of value and development of labour potential. The staff of high-tech enterprises should possess a unique combination of different skills and abilities.

The main characteristics of the labour resource of high-tech enterprises vary according to the stage of the product life cycle. Thus, the scientific component decreases and the importance of professional working skills increases with changes in the personnel structure from the first stage of conducting market research to the last and seventh stage of testing products.

The qualitative characteristics of personnel can be influenced, among other things, by changing the number of specialists and workers employed at one stage or another. In this regard, given the need to strengthen some of the stages, it should be possible to start changing the qualitative or quantitative composition of the staff.

Authors base the calculation of the labour resource potential on the vertical relationship of distribution of labour resources at every stage of the product life cycle and suggest expressing by the formula:

$$PvL=\sum k_n L_n, \qquad (2)$$

where L_n is the labour resource at the n-th stage.

The presented method allows human resources to be systematically managed across the entire product life cycle.

Method for the determination of the financial resource potential of knowledge generation.

The financial resources of the enterprise consists of money-capital (equity, debt and raised capital), used to generate assets for production and business activities with the aim of making a profit.

Sources of financial resources largely depend on the institutional form and form of ownership of the enterprise. As high-tech enterprises are mainly financed from the State budget under Government order, this inevitably involves the complexity of harmonising the annual financial security. If we consider the funding of the entire product life cycle, the money-capital distribution also occurs in stages. This is due to the specifics of the work since the validity of the assigned tasks must be verified at each stage; in the case of discrepancies, the stage must be repeated, implying additional expenses.

One of the problems in the calculation of the financial resource potential is the determination of the indicators on which basis the analysis will be carried out. Authors suggest some indicators to variety of financial resource: the amount of direct and overhead costs, the value of the company's assets, salary costs and other.

An important feature of the high-tech enterprise complex is the "closed" nature of the work, which entails the unavailability of many generally, accepted financial indicators. For this reason, the basis adopted consisted in the aggregated average wage paid to employees at a particular stage.

Authors suggest calculating of the financial resource potential, which assume a vertical relationship of distribution of financial resources between the stages of the product life cycle by the formula:

$$PvF=\sum k_n F_n, \qquad (3)$$

where F_n is the financial resource at the n-th stage.

The financial resource potential reflects a complete picture of the distribution of the financial resources, allowing the possibility of their optimisation if necessary.

Method for the determination of the material resource potential of knowledge generation.

In terms of material resources, we refer to those means of production or the part of working capital that is fully consumed in the production cycle, with the whole of their value being transferred to the finished product and their use properties changing or being lost in the production process. It should be noted that resources also include the production of tools that are used in the manufacture of products.

To material resources in high-tech enterprises can also be attributed, among other things, means of production such as personal computers. This is due primarily to the fact that the main product in such enterprises is the result of intellectual activity obtained with the help of computer technology.

In this regard, when calculating the resource potential of the material, it will be appropriate to use the indicators of the technical re-equipment plan expressed in monetary terms. This indicator is very important in the context of the fulfilment of the state order, since the technical re-equipment plan is often coordinated with the parent organisation once a year, virtually eliminating the possibility to change the final amount; however, this leaves open the possibility of the redistribution of material resources within the product life cycle. Therefore, the distribution potential of material resources must be calculated separately for each stage of the product life cycle.

The determination of the material resource potential is also based on the vertical relationship of distribution of material resources at every stage of the product life cycle and can be expressed by the formula:

$$PvM=\sum k_n M_n, \qquad (4)$$

where M_n is the material resources at the n-th stage.

By analysing the obtained results, it will be possible to identify resource zones and problem areas, allowing material resources to be appropriately redistributed within the product life cycle.

Method for the determination of the information resource potential of knowledge generation.

One of the specific features of high-tech enterprises is the limit they set on the possibilities for the transfer of information and technology. Information conditions for the functioning of enterprises entail particular secrecy requirements, limiting cooperation and technology transfer.

Another feature of high-tech enterprises is the high intensity of the research activity, determining the specificity of the content of information resources. Here can be considered specialised software, high volume databases, large number workstations equipped with personal computers, high value computer equipment and others.

In this regard, it makes sense to identify possible indicators of information resources of high-tech enterprises:

- number of application software licenses used;
- number of users of application software;
- number of equipped workstations;
- volume of databases;
- number of database users.

When calculating the resource potential of the information, it is necessary to determine the value of each indicator at each stage of the life cycle, to summarise and standardise across the largest possible information resources.

The calculation of the labour resource potential is based on the vertical relationship of distribution of labour resources at every stage of the product life cycle and can be expressed by the formula:

$$PvI=\sum k_n I_n, \qquad (5)$$

where I_n is the information resources at the n-th stage.

Method for the determination of the horizontal resource potential of knowledge generation at the n-th stage.

This method not only allows the potential use of resources to be determined at each stage of the product life cycle but also to be redistributed, thus supporting the most efficient use of resources within each stage.

Authors calculate the horizontal potential of the application of resources to generate knowledge at the n-th stage of the product life cycle. The calculation base on previous studies as additive term formulae with weighted coefficients:

$$P_n=k_1K_n+k_2L_n+k_3M_n+k_4I_n, \qquad (6)$$

where K_n is the financial resource at the n-th stage of knowledge generation;
L_n is the labour resources at the n-th stage;
M_n is the material resources at the n-th stage;
$I_n$is the information resources at the n-th stage.

In order to evaluate the specific types of resources, it is necessary to determine:

- 1. Accrued salaries normalised by the number of employees involved in implementing specific stages (stages) in the product life cycle.
- 2. The proportion of the labour force at every stage of the product life cycle, equated to the proportion of workers responsible for the implementation of this stage.
- 3. The distribution of material resources based on the cost of the constituent technical re-equipment plan for each stage of the product life cycle normalised across the entire technical plan.
- 4. The proportion of information resources according to the share of IT support at every stage of the product life cycle.

A comparison of actual and theoretical values will allow the distribution of the share of each of the resources to be adjusted within each stage, thus optimising the realisation of the tasks at the particular stage.

3. Research procedures

In order to assess the actual resource potential of knowledge generation, the study used the 2015 data production activities of one of the large enterprises operating in the Russian high-tech sector.

Authors measured at every corresponding stage of the product life cycle and compared with the theoretical values for actual data on the use of resources. To obtain theoretical values of resource allocation, authors interviewed with senior and middle managers at the level of Deputy Director General. Actual measurement consists of accurate data since, in this particular enterprise, different departments carry out every stage of the product life cycle.

As a means for evaluating financial resources, we identified accrued payroll, normalised by the number of workers participating in the realisation of a certain stage of the product life cycle. The proportion of the labour force at every stage of the product life cycle was equated to the proportion of workers responsible for the implementation of this stage. To remove the question of the individual competencies and skills of individual employees, only qualified professionals conducting research and development on high-tech enterprises were considered during the study. In addition, in order to focus on the qualifications of the selected workers, only those research teams were taken into account that did not permit any violation of the terms and quality of scientific and technical work on the high-tech enterprises in the framework of the execution of the State requisition, indicating a highly skilled, relevant labour force. The distribution of material resources was determined based on the cost of the constituent technical re-equipment plan for each stage of the product life cycle, normalised across the entire technical plan. The proportion of information resources is evaluated according to the share of IT support at every stage of the product life cycle.

These stages of manufacture of the product percentages of financial, human, material and information resources were then normalised for each stage in order to obtain the allocation of resources at every stage of the product life cycle.

In order to illustrate the proposed methodology for high-tech companies in the region, the authors present their institutional spiral of knowledge generation in the development of high-tech products (Figure 1).

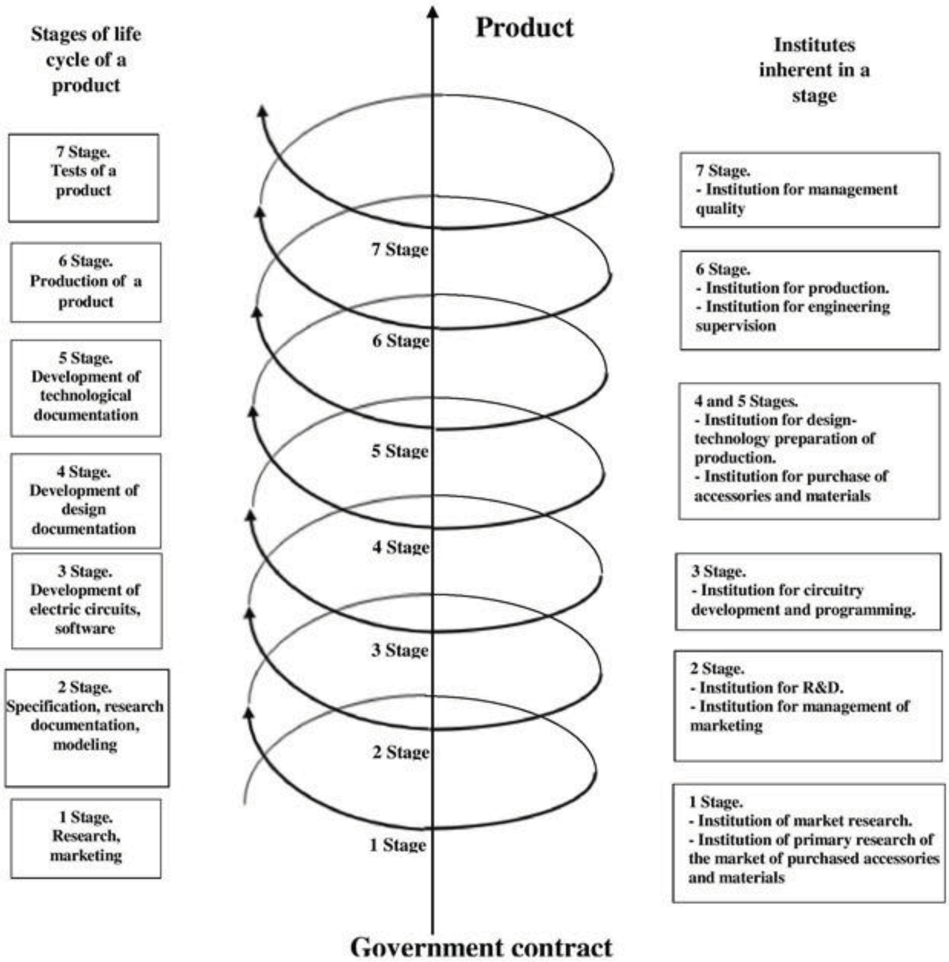

Figure 1: The institutional spiral of high-tech knowledge generation

The proposed institutional spiral of high-tech knowledge generation helps to increase the efficiency of each stage.

The first stage consists of market research and the development of documentation for participation in various tenders and competitions. The condition for the transition to the second stage is the obtaining of a government contract. When using a primary market research institute, the quality of purchased materials and components is greatly improved in relation to the institutional approach to the analysis of marketing and tender documentation. As a result of market analysis, the institute improves the quality of research into possible approaches to developing new products and, as a result, increases opportunities to participate in the larger of the projects of greatest interest. When applying institutional design in the first stage, the timing of receipt of orders is reduced, increasing the possibility of participating in projects on terms that are more favourable.

At the second stage the terms of reference are defined, research documentation prepared and modelling carried out. The ability to advance to the next stage may be considered in terms of completed preliminary design, technical proposals and scientific-technical report. The realisation of an institution of management development reduces research time as well as leading to increased accuracy and thus the possibility of creating more proactive enterprise standards. The use of a marketing management institution can reduce the time taken for the issuance of technical proposals for the acquisition of market research components. The result of using institutions of knowledge generation is an improvement in the accuracy of preparation of technical specifications, reducing the likelihood of errors in subsequent stages.

In the third stage, electrical circuits and software are developed. Accordingly, completed computer programs and electronic circuit designs in the form of technical reports and procedures are a necessary basis for the transition to the fourth and fifth stages. As a result of using an institution of circuit design and programming, the time taken to develop electrical circuits and to write computer programs is reduced.

At the fourth and fifth stages, the design and technological documentation is developed. The transition to the sixth stage consists in a complete design and technological preparation of production system, expressed in technical reports, standards, conditions and prescribed processes. When using an institution of design and technological preparation of production, it is possible to increase the number of created new technologies that affect the efficiency of production. Because of the use of an institution of purchasing components, the quality of supplied materials is increased. Following the introduction of the institutions of knowledge generation, the accuracy of the design and description of technological products is increased, reducing the likelihood of errors in production.

At the sixth stage, available products are produced whose consistent quality is a condition for the transition to the seventh stage. With the use of an institution of production, new equipment can be reallocated and used more effectively, allowing work to be carried out more quickly. With the introduction of an institution of technical control, the accuracy of technological processes is increased. When applying institutions of knowledge generation, the reliability of products is increased and defects correspondingly reduced.

At the seventh stage, testing of the product is carried out both independently and at the site of use and the product is introduced into trial operation. The outcome of this stage is the successful handover of the finished product. In applying a quality management institution, the possibility of accidental changes to manufactured products is excluded. Because of the use of institutions of knowledge generation, commissioning dates are reduced and the number of warranty repairs is reduced.

The implementation of an institutional spiral of high-tech knowledge generation has the capability of reducing the level of uncertainty throughout the entire product life cycle, and, consequently, to reduce lead times and improve the quality of all work performed.

4. Results of empirical research

The knowledge generation systems of high-tech enterprises have been studied based on the above techniques with the following results: when determining the labour, financial, material and information resource potential of knowledge generation theoretical and actual values were obtained (Table 1.).

Table 1: Distribution of the theoretical (T) and actual (F) values of the elements of the vertical resource potential of knowledge generation (%)

Stages of the PLC	Vertical distribution of resources							
	Labour		Financial		Material		Informational	
	T	F	T	F	T	F	T	F
Research, Marketing	19	14	10	13	16	16	5	12
Modelling	19	13	13	15	11	17	9	9
Software	15	12	13	9	16	15	9	27
Construction	15	12	10	12	19	23	9	4
Development of technologies	15	17	10	18	22	13	5	8
Product Manufacture	11	16	17	18	5	6	39	22
Product testing	6	16	27	15	11	10	24	18
Total:	100	100	100	100	100	100	100	100

A comparison of the empirical data and weighting coefficients of the theoretical vertical potential of the use of resources shows significant differences between the actual and theoretical values of each type of resources used at each stage of the product life cycles.

5. Directions for optimal use of resources

An analysis of the empirical data allows us to formulate the following direction for the optimisation of resource use for each type of resource separately and at every stage of the life cycle of the high-tech product.

It is expedient to reallocate labour resources, while reducing them at the stages of manufacturing and testing of products for market research and marketing, and when developing the product requirements document (PRD) and research documentation.

Financial resources must be reallocated, while reducing them to the stages of the development of technological and design documentation, research and marketing, and increasing them at the programming and testing stages.

It makes sense to reallocate material resources, reducing them at the modelling and design stages and increasing them at the technology development stage.

It is appropriate to reallocate information resources, reducing them at the research and marketing stages, as well as at the stage of programming and increasing them at the stages of development of design documentation, manufacturing and testing of products.

When carrying out research and marketing analysis at the first stage of the life cycle, it is advantageous to examine the use of labour and material resources with a view to reducing them. It can be assumed that it is preferable for a prior expert evaluation of the proportion of use of these resources to take place. In other words, it is possible that the solution to the problems of research and marketing analysis of the future product can also be developed with a smaller personnel structure and a lower equipment resource requirement.

During the second stage, when developing technical specifications and researching documentation, there must be a significant reduction in the proportion of material resources, perhaps by increasing the number of employees and improving the quality of staff. This is altogether feasible since we observed a significant reduction in the actual level of use of the labour force compared with the theoretical estimate.

During the third stage of the development of electrical schemas and software, it is necessary to decrease the share of information resources, again due to the increase in staff numbers, as well as to improve the quality of personnel management. It should be noted that the three-fold difference between the theoretical estimates and the actual level of use of information resources locates the actual problem of optimising of information activities in the realisation of the third stage of the product life cycle.

In the fourth stage of the product life cycle, consisting of the development of design documentation, the impact of knowledge generation can accelerate a significant reduction in the proportion of material resources, as well as result in a moderate increase in the use of information resources, the actual significance of which is well below the modelled level.

In developing the fifth stage of technical documentation, it is expedient to reduce the proportion of financial and information resources. This is possible by increasing the degree of involvement of labour and material resources. In other words, there is a possibility to make financial savings through optimal reallocation efforts in the realisation of the fifth stage of the product life cycle.

During the sixth stage of the life cycle – the product manufacture stage – a slight decrease in the labour, financial and material resources by means of increasing the share of information resources will lead to an optimisation of the processes of knowledge generation.

Analysis of the distribution of resources at the seventh stage of product testing shows the need to reduce the proportion of the labour force along with a possible increase in financial resources. This is all the more possible because the actual level of use of manpower at this stage is almost twice the theoretical estimate of the contribution of labour in order to complete this stage of the product life cycle.

The formulation of a direction for the optimal use of resources generated at each stage of the life cycle provides an opportunity for savings and permits the most rational use of all kinds of resources.

6. Conclusion

With the development of the method of creation of high-tech knowledge, based on the original model of the resource potential of knowledge generation, the following theoretical and practical results were obtained.

First, a theoretical methodology for assessing the capacities of the company in the realisation of intellectual activity.

Secondly, authors produced an institutional spiral of high-tech knowledge generation, the implementation of which has the capability of reducing the level of uncertainty throughout the entire product life cycle, and, consequently, to reduce lead times and improve the quality of all work performed.

Thirdly, the actual proportion of allocation of resources at every stage of the product life cycle in the production of large enterprises in the high-tech sector is determined based on empirical research.

A comparison of the theoretical and actual resource potential of knowledge generation allows a direction for the optimisation of resource use in the economy to be defined; effective resource management ensures the efficient development and manufacture of new products.

The theoretical significance of the research is the development of a methodology for assessing the efficiency of the generation of knowledge in high-tech enterprises. The practical significance of the study consists in the possibility of using the proposed method in high-tech enterprises in order to increase the efficiency of the processes of knowledge generation and optimise the use of various resources of high-tech enterprises.

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