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RESEARCH TEAMS' HUMAN CAPITAL

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RESEARCH TEAMS' HUMAN CAPITAL

Adopting a Bourdieusian perspective, human capital of research team in the paper is understood as the configuration of the active properties of individual team's members and the distribution of differences of their active properties. The paper describes a research team as an ensemble of social distinctions determined by a distribution of "active properties" of the team members (educational, research, administrative and media characteristics) and analyses their empirical distribution.

The study is based on the consideration of sociological factors of research teams' performance. The paper discusses in depth the performance of research team (from a sociological point of view) and the relationship between the performance and the social management efficiency. It is prouved that the performance depends on the efficiency of human capital management research team. These distributions show how holistic properties of the field develop, how they relate to individual agents' properties and how individual researchers "fit" into science.

JEL: I2, I28, J24, O32

Keywords: human capital, scientific capital, research and development, laboratory, performance, efficiancy, research management

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Introduction

Lately, economists, politicians and sociologists have been paying increasing attention to the activity of research groups and individual researchers. This is undoubtedly related to modernization and development of innovation economics. Although such activities have been studied thoroughly yet since the 1960s, so far neither conventional research methods nor standard analysis procedures have been established. Most progress has been attained in the analysis of economic aspects, resources and results of the research groups' activity. Among its sub-topics, effectiveness is the one that attracts most attention[Gokhberg and all, 2013]. It is usually defined as "a measure of the aggregate of all results achieved during a research or a measure of goal achievement and outcome of an R&D project." Research efficiency is also studied rather often and is referred to as "a measure of correspondence between effectiveness of R&D activities and consumed resources"[OECD, 2002].

Human capital is another important aspect often considered to be an integral part of the analysis of organizational activities, including research teams' activity. It is usually believed to be equal to a number of economic indicators of efficiency, but can also be regarded as a form of investment in staff education and professional training.

Professional training and the timely identification of the demands of new skills assume increasing importance as the technological environment is constantly renewed. This renewal is a result of technological, product-related and other innovations or their applications, all of which lead to the emergence of new requirements for personnel knowledge and skills. Unstable markets, globalisation and short product life cycles force companies and employees to master new skills to maintain a competitive advantage [Gackstatter et al, 2014]. Since the 1980s, Lundvall has stressed the close connection between innovations and human capital of institutions among with new forms of training needed for their implementation, namely, interactive learning [Lundvall, 1985, 1992, 2002].

Policymakers should develop special programmes to improve the ability to innovate [Meissner et al 2014]. The development of this ability in researchers, engineers and technicians should be part of larger programs for the adoption of new technologies and products. The ability to innovate is determined by the qualifications, skills and mobility of staff. In turn, the mobility of researchers and the transfer of their skills and competencies play a crucial role in the diffusion of innovation.

We considere the performance of research team (from a sociological point of view) as directly related to social management efficiency. Performance depends on the efficiency of human capital management research team.

This study is based on the analysis of sociological factors of performance of research teams. Economic indicators of performance weren't considered in this project.

Methodology and Approach

Human capital is defined as "an aggregate of knowledge, skills, motivations and energy of an individual that can be used for production of goods and/or services." [Romer, 1990] This definition focuses on future profits gained through investments in human resources at all levels. Such understanding of human capital is linked to the concept of the scientific and technical revolution.

However, even if we adopt a broader concept of human capital, such approach to the analysis of the activity of research groups does not seem to us fully relevant as it disregards several significant aspects of organization and functioning of science, a scientific research and researchers.

We are convinced that the approach suggested by the genetic structuralism[Bourdieu, 1975, 1988; Karady, 1977, 1979;Lebaron, 1997]is by far more productive. It offers necessary prerequisites for a complex analysis of science and its institutes both on macro- and micro-level. Individual researchers are considered as individual agents (actors) producing scientific knowledge, and R&D laboratories and institutes represent collective agents. According to the postulates of the genetic structuralism, a basic structure that is a condition and a prerequisite for scientific practices is referred to as the scientific field[Bourdieu, 1984; Barnes, 1982; Bloor, 1976, 1983].It is a multidimensional social space where each individual or collective agent (such as research laboratories) occupies a certain position and is involved in competition for scientific recognition.

The scientific field can also be regarded as a distributed system or a social network [Chalmers, 1990; Collins, Pinch, 1982] that consists of positions held by individual and collective agents who interact between themselves, and evolution of each agent is determined by his neighbours' behaviour.

Agents (especially collective agents, such as, for example, research institutes or editorial boards of scientific magazines) are characterized by complex internal structure. However, this complexity does not reveal itself in their interaction and thus in the analysis of the scientific field they can be considered as relatively simple objects boasting of a small number of effective degrees of freedom.

The scientific field can be distinguished as an independent subject of study, and we can name three important reasons for why such a distinction is feasible and productive for the purposes of our research. First of all, this approach implies *relative* autonomy of scientific practices from any external influence, be it political, administrative, state or economic one. Second, there exist stable invariants of scientific practices that can manifest themselves as norms, standards, traditions and movements. Third, all resources needed for production of a scientific discourse as a specific kind of a social game are limited: there is always a moderate number of R&D institutes, positions, awards, magazines, grants and so on. Scanty possibilities lead to inevitable reduction in potential complexity of researchers' practices to a restricted set of scientific positions.

The structure of the scientific field is defined by the distribution of the specific capital possessed by the agents in the field. Combination of various capitals determines how integral the field in question is and describes concordant changes of the key features ('active properties') of its agents. Different kinds of capital – cultural, educational, scientific, administrative and social – are thus regarded as variables that determine the scientific field and all other variables. Distribution of those kinds of capital (that is, relations between them) subordinates the characteristics that can be measured directly. As a consequence, we can substitute a description of a large number of 'microscopic' variables by a description of two or three substantial 'macroscopic' ones. The development of the structure of the scientific field is a result of a fluctuation rise in active properties of researchers, enforced by influences and powers, external to the field itself.

Capital is an analytic category constructed by a sociologist on basis of the empiric data he possesses with regards to agents' active properties. Different kinds of capital are to be defined separately in each case, since they represent invariant field properties, and the latter in turn depend on authority and power distribution inside the field.

Every field is characterized by a specific capital that determines the functioning of that field and explains behaviour of individual or collective agents that act in it. For example, as far as the political field is concerned, its main capital is the political capital, and respectively, the economic or financial capital dominates over the economic field.

Empirically, each capital is a factor constructed through statistical procedures of multidimensional scaling [Bourdieu, 2004] that distinguishes between agents in the sample by a certain characteristic. Such a factor can notbe attributed before a statistical analysis has been held; on the contrary, the former is an independent resut of the latter.

We have to underline two peculiarities of the notion of capital. First of all, since capital is understood as a configuration of active properties, it therefore implies rejection of one-dimensional and "linear thinking, which only recognizes the simple ordinal structures of direct determination" [Bourdieu, 1979, p.119], and urges to analyze interrelated relationships objectified in the field in their totality. Capital is a system of active properties where each of the properties enforces the rest of them and this interaction results in total, ultimate interdependence of those properties rather than the absence of any dependence. Thus, if a sociologist chooses to use capital – a multidimensional configuration of agents' properties – as an explanatory principle for scientific practices, instead of an ordinary understanding of dependence between the agents' properties, he/she can construct several aggregate factors that would explain the whole varierty of practices.

Secondly, the notion of capital is closely associated with the concept of field. That implies that agents' properties are not all simultaneously operative. Only those properties specifically related to the field in which they are objectified or internalized: different fields have their own systems of active properties that equal to capitals. "The specific logic of the field determines those which are valid in this market, which are pertinent and active in the game in question"[Bourdieu, 1979, p.127].

Capital determines agents' practices. At the same type, as it is an abstract 'ideal type', a capital never reveals itself in 'pure state' per se, as it can only exist in a specific form. Agents' practices can be explained through capital, but a sociologist cannot study it directly since it has to be constructed as an analytical abstraction using methods of mathematical statistics.

Our interpretation of the notion of capital largely disagrees with its widely accepted interpretation offered by T. Schultz or G. Becker and his successors (M. Blaug, R. Laird, J. Mincer). They believed that the economic factor was the most important one and, more specifically, attributed a large weight to the profitability of investment in education and professional training for economically active population [Schultz, 1971; Becker, 1964; Blaug, 1976; Mincer, 1974, 1994].There is no doubt that human capital is not limited with knowledge and human capacity to work, neither can it be considered just a spending factor; it is a major social condition for development of science and innovation. We consciously leave aside the investment component, albeit acknowledging that certain aspects of human capital (active properties of individual and collective agents) can be enforced through purposeful investment. The latter do not necessarily have to be centralized or financial.

As applied to scientific production, ‘human capital’ is an aggregate of active properties, seen as resources of scientific practices that regularly return interest to a researcher. That profit can be denominated in specific stakes of a game in the scientific field in a long run. We distinguish between individual human capital of an individual researcher and collective human capital of a research group. In our concept human capital is a *characteristic function,* which is a function of state of respective independent parameters (agents’ active properties). Once parameters values are known, this function and its derivatives describe all social properties of an agent that we are interested in. Human capital can also be used in order to explain scientific patterns –any sequences of events of scientific production–, as the distribution of human capital conveys explicitly the state and dynamics of the production’s social relationship.

Individual human capital of a researcher can be measured by the following groups of indicators:

- Educational properties: basic education, higher and postgraduate education, a scientific degree, further professional training, etc.;
- Scientific properties: affiliation with a scientific movement, a number of publication, publications translated into other languages, participation in scientific life (conferences, seminars, etc.), scientific awards and other tokens of recognition from the colleagues;
- Administrative properties: positions held in scientific, educational and state institutes; membership in editorial, academic and scientific boards; participation in expert examinations, work groups and and commissions, etc.;
- Media properties: media publications of an agent or about him/her, including reviews, public lectures, participation in TV- and radio shows, personal blogs and web-sites.

Respectively, collective human capital is a distribution function of active properties of a group.

That is why, when speaking about a subject of social administration, we will always be referring to the human capital of a research group as an invariant that determines conservation of main properties of a group while the latter undergoes various changes.

Analysis of relationships exisiting within scientific production allowed us to construct R&D team as a subject of sociologic study. Addressing those relationships again, we decided to distinguish the most significant ones and established the study procedure. It allowed us to outline the direction of our research and its goals. Then we realized that practical implementation of the results of our study enables us to map out concrete measures that could contribute to resolving the problem of rational transformation of research and development groups.

According to Merton [Merton, 1979], scientific communities arise before democratic social structures. In scientific communities, scholars are united not by mechanical constraints but by a specific set of values and norms, joint goals, and culture. However, the clich/e of the scientific community as a microcosm in which gifts of information are exchanged in return for recognition among equal colleagues [Hagstorm, 1975] has been shown to be a fiction. In fact, in the "pure" microcosm of even the "purest" science, there always remains an element of intense competition "in which the specific issue at stake is the monopoly of scientific authority, defined inseparably as technical capacity and social power" [Bourdieu, 1975, p. 19].

From a sociological viewpoint, the production of modern scientific knowledge occurs in "a social field of forces, struggles, and relationships that is defined at every moment by the relations of power among the protagonists" [Bourdieu, 1991, p.3]. The structure of this type of scientific field or, what amounts to the same, space of relationships is characterized *grosso modo* by the distribution of scientific capital between the agents and institutions that operate in the field [Bourdieu, 1997, p. 14–21]. Roughly speaking, the concept of scientific capital highlights the process of accumulating specific resources and benefiting from the academic and administrative status that result in both reputational and power effects. Theoretically, social regularities of the knowledge generation are produced and reproduced through the distribution of scientific capital and the interests of the individual and collective agents in this field (cf. [Bourdieu, 1985, p.724-725]). Scientific capital is an invariable property in the scientific field that is connected to the allocation of specific scientific power and recognition. Scientific capital takes its form and content from the scientific field within which it is used. Scientific capital is country-specific and its currency varies across different national social spaces. According to Bourdieu, scientific capital is a configuration of active properties (active in the sense that the properties represent a field of forces) that provide the agent with authority, recognition, influence, and power in a given scientific field [Bourdieu, 2004, p. 55–58]. Scientific capital tends to set ensembles of active properties of individuals within the social structure of scientific field.

Bourdieu's approach to the scientific capital has been empirically tested [Bourdieu, 1988; Brosnan, 2011; Gartorth, 2011; Hong, 2008; Lebaron, 2001; McGuire, 2011; Panofsky, 2011; Rouget, 2002].

For a critical analysis of this approach, see [Bellotti, 2011; Brubaker, 2005; Camic, 2011; Coradini, 2010; Grosetti, 1986; Jain, 2013; Sismondo, 2011].In the literature, scientific capital is also presented [Corolleur, 2004; Bozeman, 2001, 2004; Dietz, 2005; Lin, 2006] as the sum of knowledge and work-relevant skills, social links, and resources. However, Bourdieu's version of the scientific field — which has an integral character and strives to eliminate the contradictions between micro- and macro-sociological analysis, agents, and structures — seems preferable. Still, we lack a mathematical model for scientific capital, because the quantification of scientific capital does not fall outside the parameters of multivariate statistics [Lebaron, 2009, pp. 11–29]. In order to achieve the better understanding of the notion of scientific capital, in this paper a mathematical modeling approach is put forward, which describes firstly structural relations between scientific capital and both the amount and quality of social resources, and secondly probability distributions of scientific capital.

Bourdieu's concept of scientific capital exhibits three principal characteristics:

1. Scientific capital expresses the emergent quality of the set of an agent's active properties. The agent's scientific capital is examined as an attribute of unified scientific field. In this sense, scientific capital is *sui generis* the characteristic state function, which means that the condition of the scientific field can be presented as a function of scientific capital.
2. Understanding scientific capital as an integral configuration of active properties is tantamount to rejecting single-variant analysis based on "*linear thinking*, which only recognizes the simple ordinal structures of direct determination, and endeavors to reconstruct the networks of interrelated relationships which are present in each of the factors" [Bourdieu, 1984, p. 107]. Scientific capital is a system of active properties in which each quality strengthens the others.
3. The active properties are the efficient characteristics "that are selected as principles of construction" of the scientific field; "are the different kinds" of scientific capital [Bourdieu, 1985, p. 724]. Each active quality receives its value and efficacy from the regularities of the scientific field [Bourdieu, 1984, p.113].

Active properties are allowed to operationalize as socially significant resources in the production of scientific knowledge. Here, we refer to resources that regularly result in a specific gain, a stake in the social game bounded by the scientific field, and that endure for a long period. In this type of interpretation, scientific capital determines the chances of an agent's attaining recognition or an administrative post. From this perspective, maximizing scientific capital can serve as the conceptual focus of the scientific field. (see [Bordley, 1983; Chernyak, 1992]).

Bourdieu's conceptualization of capital is related to "the set of actually usable resources and powers" [Bourdieu, 1984, p. 114]. In general, scientific capital may be defined as "accumulated labor… which, when appropriated on a private, i.e. exclusive, basis by agents or groups of agents, enables them to appropriate social energy in the form of reified or living labor" [Bourdieu, 2002, p.280]. Bourdieu's usage of the concept of "social energy" is a metaphorical but fruitful extension of scientific capital. According to the general methodological approach, the state of a scientific field is defined if values to all the quantities used in the sociological investigation are determined.

We proceed from the assumption that the agent's behavior within the scientific field need not be rational but that his or her sociological explanation will be rational, which is precisely the principle of maximizing scientific capital. The agent's strategy selects high-yield combinations of the values of active properties. Each strategy seeks to reach a balance of efficiency and the stability of the agent's social trajectory within the scientific field: that is, to obtain the best results in different undefined social situations.

One of our tasks was to adapt a collective agent to the needs of scientific production, and that brought us closer to the necessity of introduction of *social administration* defined as directed purposeful impact on relationships within a collective agent, on its relationships with scientific production and on the modification of individual agents' properties.

However, a well-formulated problem of social administration requires concrete information about its goal, and thus, about new desired properties of a R&D team. Moreover, we shall not forget that the aim is also determined by the conditions of functioning of a group and external powers that might have certain impact on the subject of social administration.

In order to take into account the above mentioned conditions and external influences we have chosen an invariant as the object of social administration, and namely, human capital. It is clear that human capital in a R&D group is managed through changes in its configuration, that is, through transformation of the relationships between active properties of individual agents, members of the group (see [Shmatko, 2011]).

Research methodology and sample layout

The task of human capital measurement has been set within the framework of the project called Factors Of Efficiency In R&D Teams' Activities.[2] During this project, we have studied research and development groups from the Russian Academy of Sciences (RAN), the Russian Acdemy of Medical Sciences (RAMN) and the biggest Russian universities, such as the Lomonosov Moscow State University (MGU) and the Mendeleev University of Chemical Technology of Russia (MHTI).

We have conducted a survey in 13 R&D groups chosen via purposive sampling. In total, 233 individual researchers were interrogated. The R&D teams were chosen for participation in the survey according to the following criteria:

- Experimental(rather than purely theoretical) research;
- Researcharea: chemistry, biochemistry, biology, biomedicine, bioinformatics;
- Group size: 10 to 25 researchers.

In such a way we have ensured a relatively homogeneous sample that allowed us to compare various indicators of each group's activities and to reveal factors responsible for efficient research group management.

Apart from this, the study included an experiment that aimed to compare formal and informal structure in a R&D team. We chose one laboratory where we interviewed both staff members and out-of-staff employees that regularly worked for laboratory's projects and/or carried out various tasks for the group. Such approach allowed us to study an interesting case and compare structures and efficiency of two forms of organization of scientific research.

Our project did not pretend to evaluate content, efficiency or scientific value of the research activities of the groups, since it requires a separate study and extensive expert work.

Unlike other empirical sociological studies on science and scientific community that had been conducted in Russia earlier, our study was based on artefact analysis as those were measurable indicators: number of diplomas, publications, conference reports, grants, contracts, membership in expert commissions, etc. rather than scientists' opinions and self-estimation. It allowed us to objectify the indicators responsible for measurement and administration of the human capital. The

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[2]HSE Basic Research Programme 2009. This purpose was developed in the frame of following Monitoring survey on Highly Qualified R&D Personnel (2010-1014).

tools for the survey included a comprehensive whole of indicators of practices and properties of bot a group in its integrity and separate individuals.

Data describing group activities were mainly recorded according to the standard indicators of scientific activities' efficiency. For example, the list of "Indicators of Efficiency of Academic Activities" of the Russian Academy of Sciences includes: reviewed publications in journals, monographs, patents, conference reports, elaboration of teaching courses, presentation of dissertations, etc. In our survey, we supplemented the list due to the fact our sample included R&D groups that dealt with experimental, empirical research and it was important to make a record of whether they have access to all necessary equipment and facilities required for their experiments. Therefore, we included in the interview questions on free access for researchers and post-graduate student employed in various projects to the following:

- Engineering, design, R&D and technologic departments and organisations;
- Experimental base (R&D production);
- Auxuliary departments (workshops, repair and maintenance services);
- Scientific equipment and experimental machinery multi-access centre;
- Centre for technology transfer;
- Centre for innovation and technology;
- Industrial park;
- Business incubator.

We made a record of educational, scientific, administrative and communicative characteristics of a head and other employees of every R&D team. All the information gathered later underwent statistical data treatment and thus we coud determine stable invariants of practices and properties and display fluctuations typical for groups that work efficiently. The statistical data treatment procedure included multidimensional scaling of empirical data collected during the survey and mathematical modeling of R&D teams' effectiveness.

Results and Discussions

Profiles of R&D teams in the survey

While studying R&D teams, it is important to ask whether a group examined is truly a team, whether the list of employees corresponds to the list of people actually working on projects of the team and whether research workers share the same conceptual approach and hold the same views.

Our survey revealed that only in three out of thirteen groups the list of employees is a meaningless paper and the real team consists of research workers from different labs and institutes. For the majority of the groups the list of employees corresponds to reality and researchers from other departments might only be invited for short-term collaboration (usually working on a small specific task) from time to time.

Only in two teams, namely in the group number 3 and the group number 7, their heads believed that their team does not really consist of like-minded people who share common conceptual approaches and ideas and stated that their researchers enjoy a large degree of autonomy.

It has to be underlined that R&D teams included in the survey are all different as far as their social structure is concerned:the list of personnel (its length and positions), age of group leaders, their experience in team management, publication activity, participation in expert commissions and other examining nodies, grant activities, etc. (See figures 1-3).

Further analysis proved that presence/absence of post-graduate students and employees under 35 is an important characteristic that has a big impact on the efficiency of R&D team's activities (Figure1). Among the teams in question, only in half of the groups there were more than 30% (which is the sample mean value) of young employees. Respective percentage in the group number 10 is lower than 20%. It shall be added that younger employees work mainly in research departments that work on scientific disciplines in conjunction with other scientific disciplines, such as biochemistry, biomedicine, bioinformatics. The same groups attract the highest number of post-graduatestudents (Figure2) that combine work on their dissertations with research planned and required by the laboratory.

Figure 1:*Young (under 35) employees' share in the R&D teams*

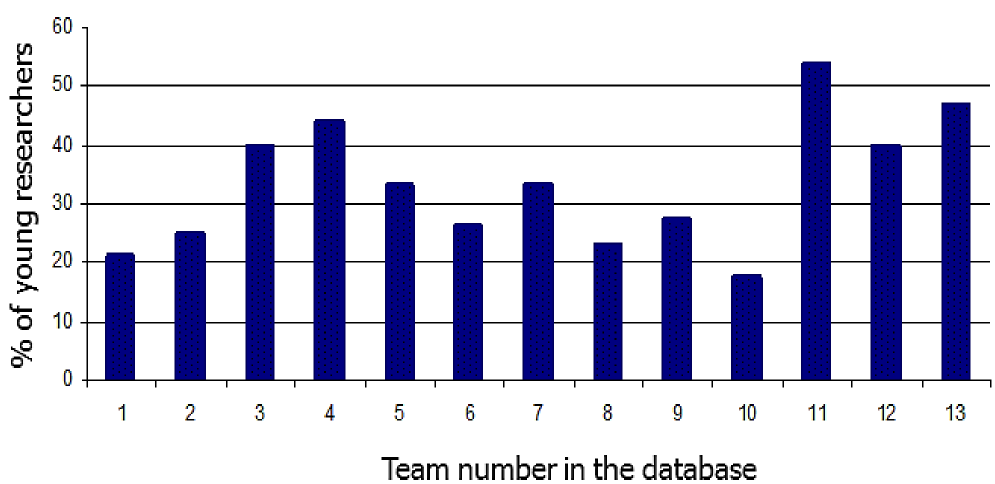
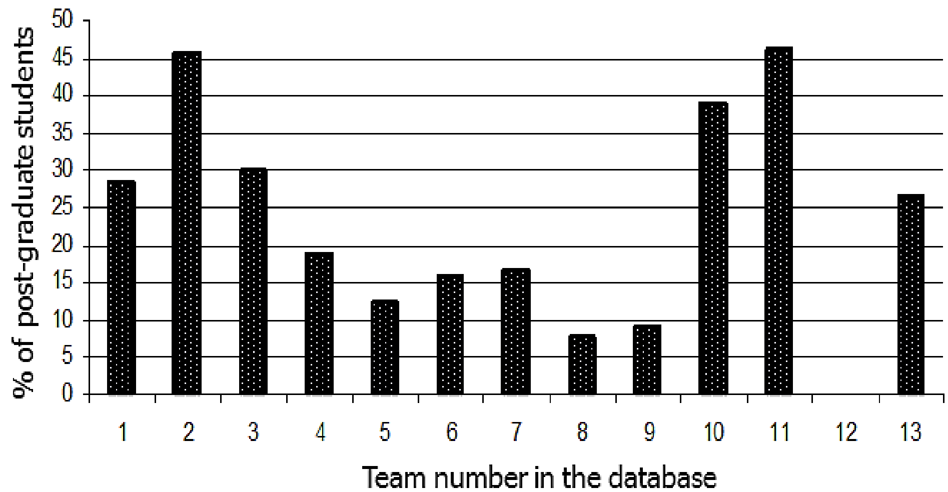
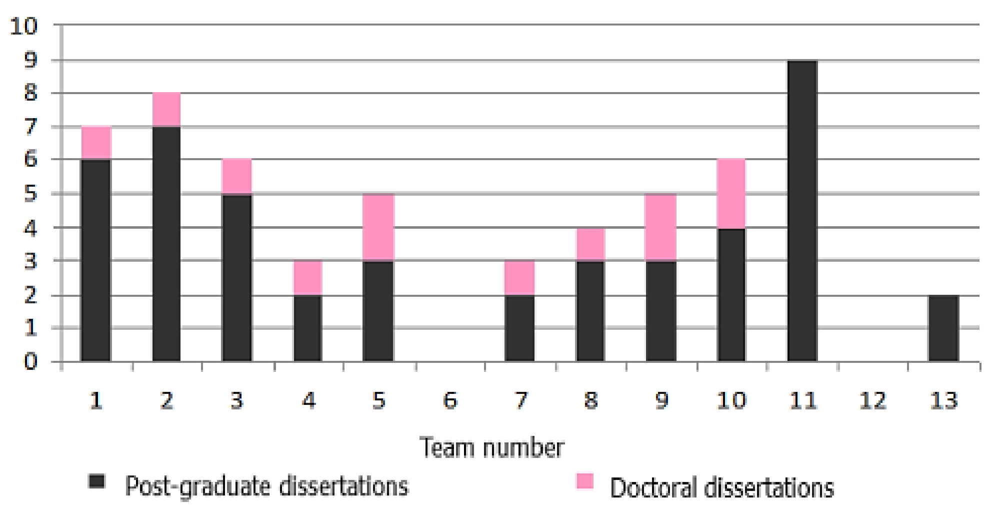


Figure 2: *Post-graduate students' share in the R&D teams*



The "number of post-graduate and doctoral dissertations, prepared and presented in a scientific department" is one of the major 'traditional indicators' of effectiveness of R&D teams. According to this criterion, the most effective R&D teams are the number eleven, the number two and the number one. Three of the teams (number five, nine and ten) presented two doctoral dissertations each in the past three years. Two of the thirteen groups included in the survey did not present any dissertations between 2006 and 2008.

Figure 3: *Number of post-graduate and doctoral dissertations presented in respective R&D teams*

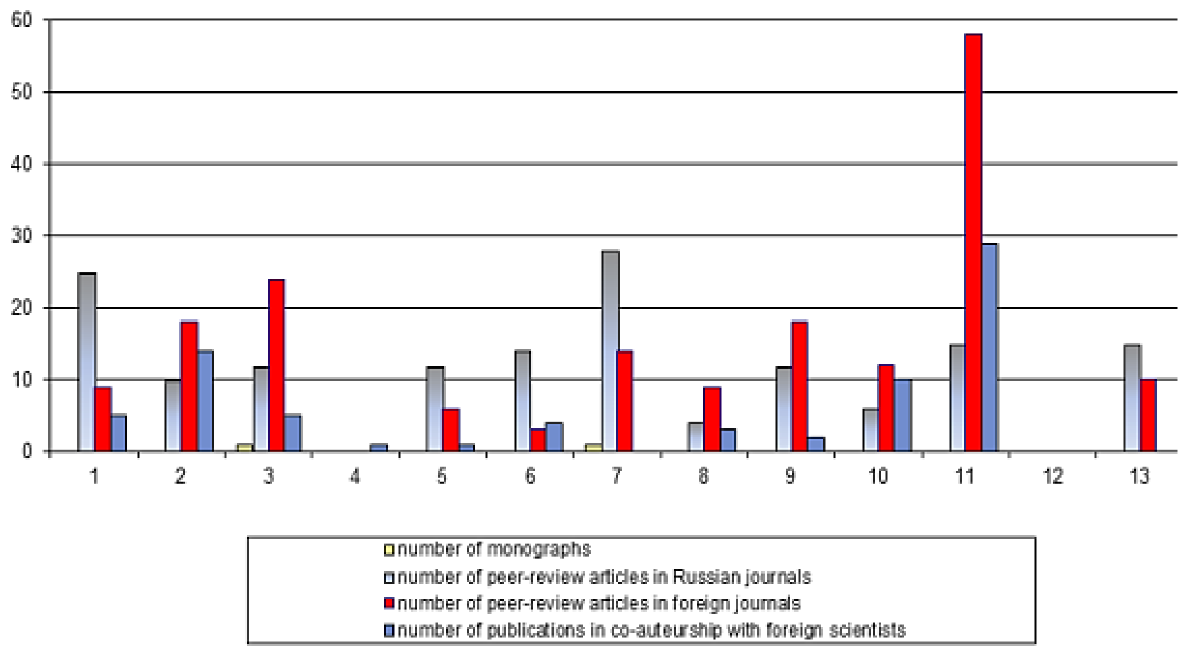


As far as the patent activity is concerned, we have to mention that it is very low in virtually all R&D teams in question. The only group that shows high activity in this respect is the team number nine: 25 patents obtained within the last three years. Five of the groups included did not register any patents in the same period, and four of them registered in the mean time from one to three patents.

The interviews with the group leaders revealed that they share rather a skeptical attitude towards patents. Some of them consider it a waist of money (for the registration/maintenance/renewal of patents); others are convinced it is a meaningless activity since, from their point view, registration of a patent does not require any significant innovations or discoveries.

Analysis of data representing publication activity of the R&D teams between 2006 and 2008 (see Figue4) points not only to the fact that the groups have very different levels of this activity but also indicates that the publication strategy of the teams also differ significantly.

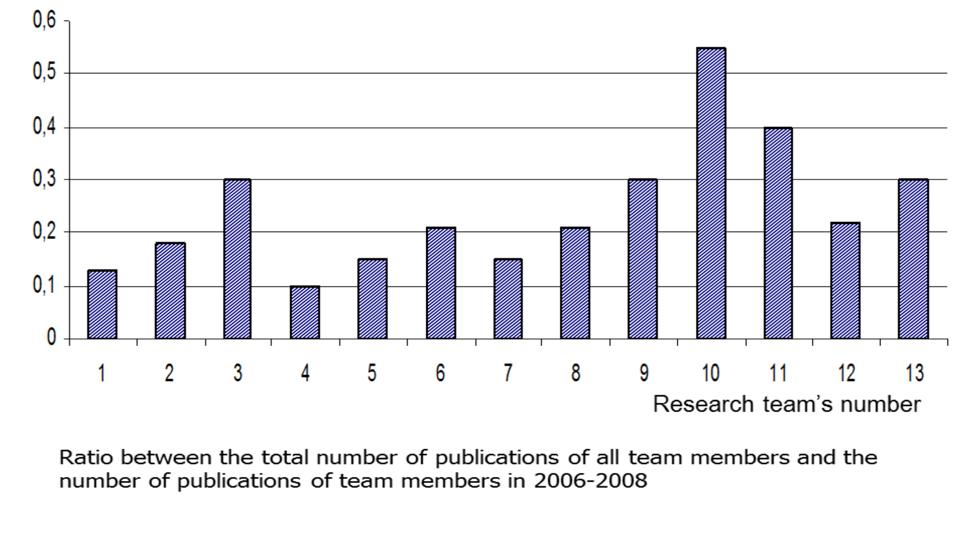
Figure 4: *Publication activity structure of the R&D teams, 2006-2008*



For example, the team number 12 has not published anything in the interim period. The team number 4 has presented one article, in collaboration with foreign partners. The team number eleven features the biggest number of publications, and a vast majority of those are articles published in foreign magazines and publications prepared in collaboration with foreign colleagues. The ratio between articles published by this team in Russia and abroad is 1:6. A similar trend to seek/prefer international publications exists in almost a half of the R&D teams: number two, three, eight, nine, ten, eleven. All of them work in biochemistry, biology or bioinformatics. One “Russian” publication in these laboratories corresponds to two or three published somewhere abroad.

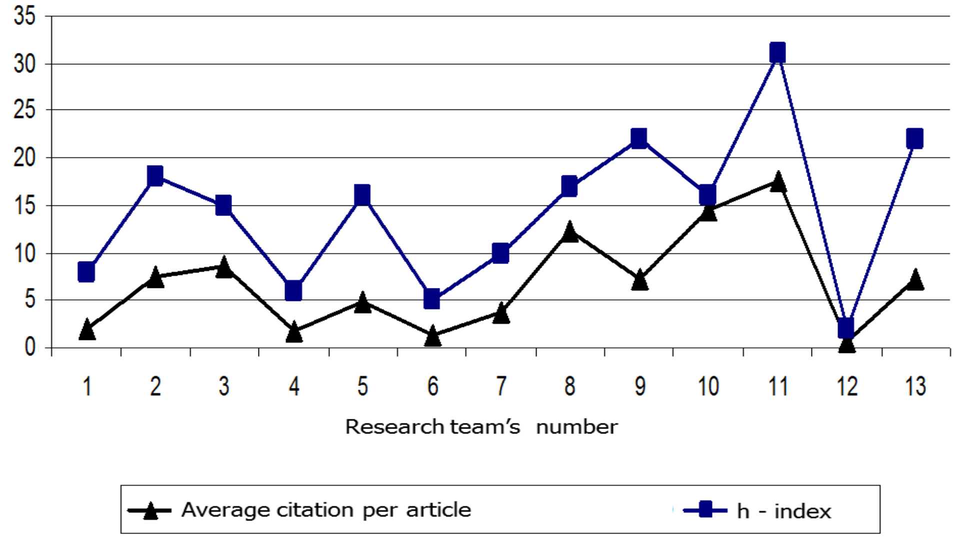
Other important indicator of publication activity is the ratio between the total number of publications of the team and the number of publications in the past three years. Our analysis proves that the groups differsignifictnly in this respect, the most active ones being number 10 and number 11.

Figure 5: *Publication activity of the R&D teams*



The data concerning publication activity of R&D team members was supplemented with the citation index provided by the ISI Web of Knowledge, namely, the Science Citation Index Expanded (see figure 6). According to it, group leaders of the teams number 11, 9 and 13 show the highest generalized Hirsch h-index: h=31, h=22 and h=22 respectively.

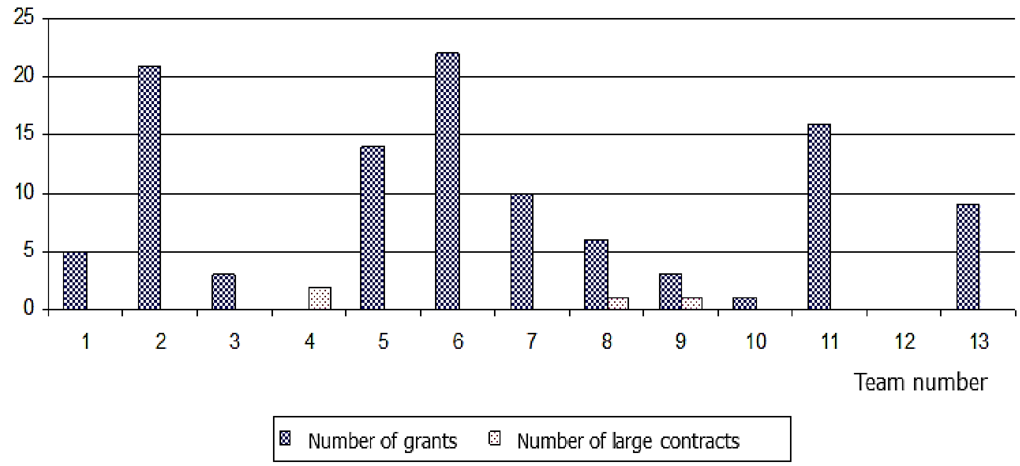
Figure 6: *Citation indexes of the group leaders of the R&D teams (ISI Web of Knowledge, 1955—2009)*



Grant, or contract, activities of a R&D team are also measured as an indicator of its effectiveness. It includes a total number of grants obtained from various sources, and contracts for R&D, engineering, design and technologic projects. We countred separately a number of contracts for implementation of large-scale projects worth more than 10 mln rubles. The data we gathered shows that only three groups worked on similar kind of projects in the past three years. Other R&D teams had smaller grants and contracts, and the teams number four and twelve did not receive any grants or sign any contracts in 2006-2008, as it was their leaders' deliberate and conscious choice.

The biggest number of grants and contracts in the interim period was received by the teams number six and two. For the number six, the main souce of funding came from various contracts with the industry, while the team number two received their grants from the Russian Foundation for Basic Research (RFFI).

Figure 7: *Participation of the R&D teams in the project system*



The total number of grants and large contracts received/signed for elaboration and implementation of the research and development, engineering, scientific design and technological projects

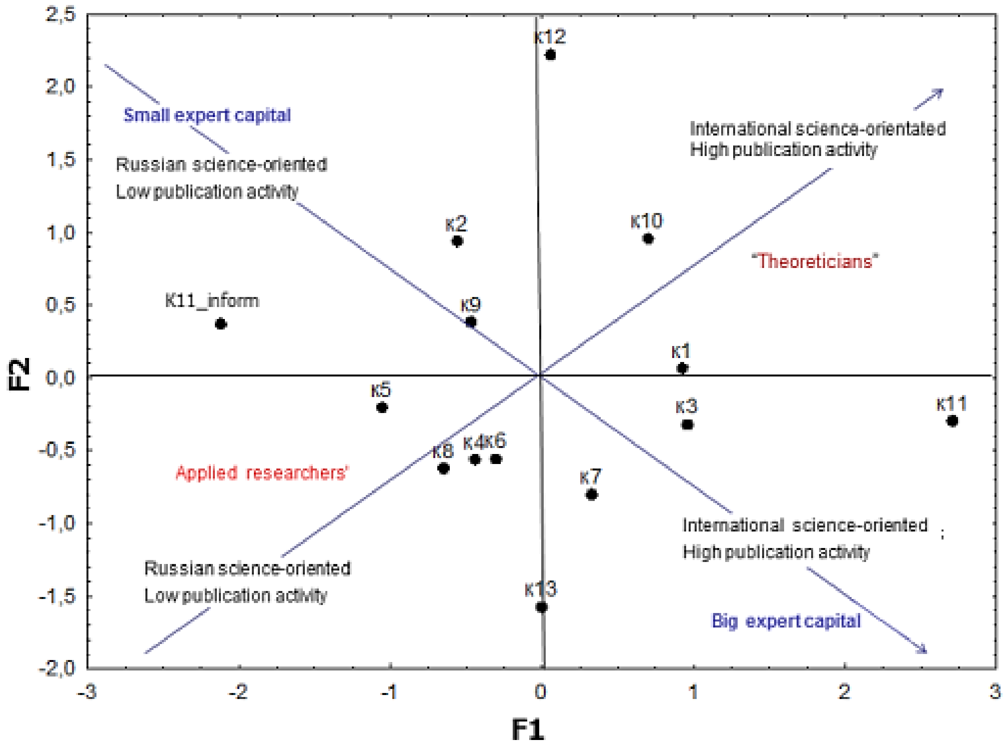
Half of the scientific groups included in our survey enjoy the infrastructure they need: either directly in their departments or they have access to all the necessary facilities. 10 groups out of 13 use shared scientific equipment multi-access centres. A 70% majority of the teams in question have an engineering base for experiments or similar auxulisary departments. Access to technology transfer centres, industrial parks and business incubator were the least demanded facilities.

Space of studied R&D teams

The information we gathered initially was subject to thorough statistical data treatment, in order to see the preliminary structure of the object of analysis. A factor analysis revealed a certain structural community of properties of some of the the R&D teams (see figure8).

The space is structured along two main and two auxiliary axes. Aggregate capital is located along the two main axes, F1 (aggregate scientific capital) and F2 (aggregate administrative capital). The auxiliary axes structure the space with regards to the expert capital and a new so-to-say-integral factor which indicates whether a R&D team is geared for integration into the international scientific society (respectively, a team can be oriented towards achievements of Russian or international science).

Figure 8: *Space of the R&D teams*



F1 – aggregate scientific capital
F2 – aggregate administrative capital

The R&D teams are located along the axis F1 (which for convenience we called "scientific capital") based on several indicators: their publication activity, participation in conferences, presence and number of employees with scientific degrees and awards, the research profile (fundamental/applied research). The teams that are located in the left part of the graph, have lower publication activity, less researchers with scientific degrees and are more interested in elaboration of applied and practical solutions in comparison with the teams in the right part of the graph.

The axis F2 – administrative capital – is formed by the teams number thirteen and twelve. On the one pole we see a team led by a man with a large number of administrative assets: he is a member of academic boards of the Russian Foundation for Basic Research, of the the Ministry of Education and Science of the Russian Federation, of the Higher Attestation Commission of the Russian Federation; he is in the forefront of his own movement in the Russian Academy of Sciences and has established a scientific school on basis of the laboratory he is a head of.

The team number twelve, with its little administrative capital, is on the other pole of this axis. As a matter of principle, the teams that are located in the lower part of our graph, as opposed to the ones in the upper part, have large administrative assets, a bigger number of employees that hold positions in scientific, educational and state institutes, are members of editorial and university boards, working groups and various committees.

As we differentiate the R&D teams by two extra factors – namely, expert capital volume and will to be integrated into the international scientific society, we can thus divide our teams in four types that coincide with respective quadrants on the Fig. 8.

Only two teams ended up in **the first quadrant** (upper right corner of the figure), the number ten and the number nine. They are international science-oriented, geared for integration in the international scientific society, have a high annual number of reviewed publications in foreign magazines. Moreover, the team number nine has registered the highest number (25) of patents among all the research groups. Both number ten and nine are working on implementation of large-scale projects in fundamental research.

The second quadrant (lower right corner) gathered R&D teams that are characterized by large volumes of scientific and expert capitals (number 11-formal, number thirtenn, number three and number seven). The leaders of these teams have high citation indexes (and during the interviews, they were actually able to name them) and actively participate in various conferences. Moreover, they are often invited as experts and are members of Russian and international programmes for science development. For example, researchers of the team number seven belong to eight expert councils, three of which are international. The leader of the team number 11-formal is a member of editorial boards of ten international scientific magazines.

In **the third quadrant** (lower left) we see four teams: number four, six, eight and five. They are Russia-oriented: their articles have mainly been published in Russian magazines and compilations, they participate in conferences and seminars in Russia, are not embedded in the international scientific ccooperation system and international professional associations. Their publication activity is rather low, they are mainly concerned with applied fields, and their projects are mostly financed through contracts they signed with Russian organizations.

The fourth quadrant (upper left) gathered four teams (number 1, number two, number 12 and number 11-informal). Among those, the number 11-informal is rather an exception, and the only common feature it shares with other teams in the same quadrant, is educational activity: all four of these R&D teams are linked to the higher education system in Russia (namely, to the

LomonosovMoscow State University, Mendeleev University of Chemical Technology of Russia and private higher educational institutions) and science pursued in the universities. The teams number one, two and twelve are mainly geared for the Russian scientific achievements, ahev low publication activity and are not integrated into the expert community. Unlike the teams in the third quadrant, these are less concerned with applied science.

Efficient management of collective human capital

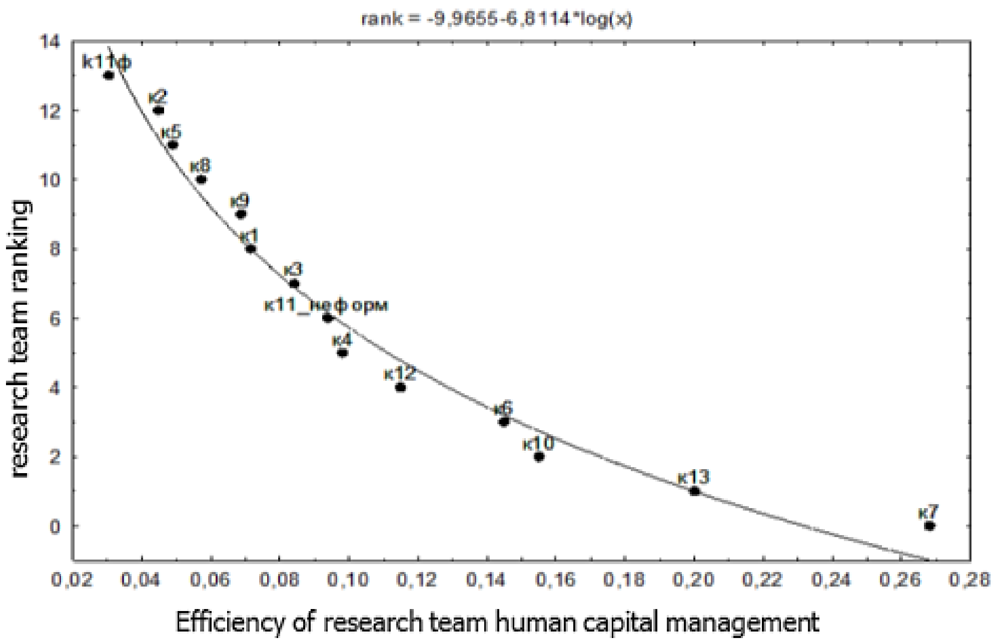
Achieving our goals, we had to elaborate a rather detailed quantitative analysis which leads to construction of incredibly long logic inferences. This multitude, in turn, prevents us from being able to choose rationally and consciously just one possible alternative, unless we recur to symbolic means that would help us formalize those processes and create an algorithm for them. Mathematics offers us a plenty of similar symbolic instruments, and as a consequence, our R&D team human capital model is highly mathematized.

Since we conceptualized human capital of a research and development team as a distribution function of social differences, we revealed a general principle that can be used as an instrument for a fine and compact analysis of limitations for human capital management in specified conditions. In mathematics this principle is called the principle of stationary action (or the principle of the least action). It postulates that R&D team's own human capital (that is, the one that corresponds to the optimum level of efficient management), stands out of the row of all other possible human capitals for the same team just given the condition that its action is stationary. In our case the principle of stationary embodies the sociological idea of stable interaction and balance between the three 'acting reasons':

- Spontaneous development of R&D team's human capital;
- Purposive control actions;
- The human capital is determined by the social conditions of scientific production.

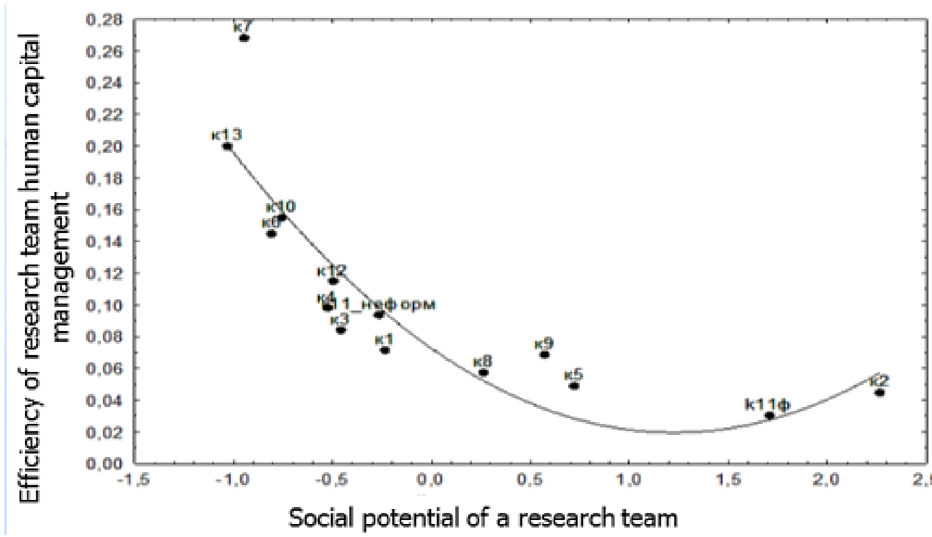
Optimality of one's own human capital is guaranteed by a certain balance between management, control, social conditions and prerequisites, and spontaneous activities of researchers [Kitova, 2014]. Naturally, optimality of any model of collective agent's human capital management in the scientific field is relative, as it's optimal only for certain conditions and will cease being optimal under other conditions. Whatever model we choose, there will always be a whole number of circumstances that were not taken into consideration when it was constructed – and thus, its optimality can be questioned. In other words, it can always be proved that an adopted criterion is a criterion for an optimal solution only if certain assumptions and limitations worked out. The problem of optimality of social control of a R&D team is not in the limitations of a mathematic model. Instead, it hides in the scientific practices themselves. There are no management strategies that would be unconditionally reliable in all situations, and there are no complete deadlocks. That's why we do not pretend that our model of optimal human capital for a scientific research and development team can find some sort of absolute extremum. To the contrary, in the first place, our conceptual model is an instrument for analysis of the current situation in the scientific production in Russia.

Figure 9:*Ranking under efficiency of management*



It turned out that R&D groups' human capital values that correspond to optimal management form a sufficiently broad class of distributions that coincide with Pearson distribution. Based on that, we defined the concept of efficient management of collective human capital as a probabilistic distance from an empiric distribution function of social differences to a theoretical distribution function that corresponds to optimal management.

Figure 10:*Ranking under social potential*



Of course, the sociological concept of collective human capital is supported by the fact it can be applied to analysis of empirically detected social phenomena. After we changed our sample, we proved that human capital management efficiency correlates with two indicators of R&D team functioning: with the number of post-graduate dissertations (the first stage of a doctorate in Russia) presented by researchers, post-graduate and PhD students of a team, and with the number of articles published in cooperation with colleagues from other countries. Such result seems very logical and proves the relevance of our definition: efficiency of human capital management cannot be independent from the production of human resources in the scientific field. The significance of international scientific cooperation can be easily proved too.

We created a space for the R&D teams we have examined using multidimensional scaling of empiric functions. Its structure can be described through distribution of specific capitals that characterize concordant changes of key (active) properties of members of all R&D teams. From the empiric point of view, every such capital represents a statistically constructed factor that embodies some invariant quality of research and development groups' space that depends on the distribution of power and authority in that space. Two axes of this scientific space correspond to volume of aggregate scientific and administrative capitals possessed by a R&D team

Distribution of scientific and administrative capitals among the R&D teams in question subordinate directly measured active properties, and thus for research purposes we can substitute a description of a large number of 'microscopic' variables by a description of two or three substantial 'macroscopic' ones.

Our research shows that factors that structure the space of team leaders of the R&D teams we studied do not coincide with the factors that determine the space of the R&D teams themselves. Even though the contribution of heads of research groups to the distribution of active properties of their teams is very big, as they have the biggest values of all measured sociological indicators, this contribution is not crucial. The space of the R&D teams has a far more complicated structure. A head of a team would typically seek recognition in the scientific world (which is revealed, amongst other indicators, in a high citation index), while the space of R&D teams is structured by such factors as cumbersome functions of active properties which we treat as aggregate volume of scientific and administrative capital possessed by the research teams.

It is worth mentioning that the efficiency of human capital management proves significant correlation between social potential of a R&D team that is our axis for the R&D teams space constructed through multidimensional scaling of weighted average social differences between members of research teams. The weighted average were calculated on basis of publication activity and recognition in the scientific world. In other words, the more efficient social control is, the lower is the social homogeneity and the sharper the unevenness of the active properties distribution is, and respectively, social practices are further divided.

In such a way, efficiency of human capital management depends on average properties of social composition of a collective agent in the scientific production.

Conclusion

With bigger or smaller success, common human capital management practices in Russia make use of methods of centralized external action on a R&D team. However, Russian experience proves that scientific achievements are relatively inefficiently regulated if exposed only to external administrative and financial measures. Thus there appeared a need to switch the focus to target influence that would be able to form R&D team's own structures that spring up on their own, besides external political or economic factors [Afanasyev et al., 2014]. These structures are invariant with respect to various changes of research practices' social conditions. It is clear that R&D team's own structures are 'by default' relevant to the essence of production of scientific knowledge and can function as prerequisites for breakthrough innovations.

Therefore, we shall not only fully take into consideration immanent properties of a R&D team, but, further on, to base our analysis on the following indisputable fact: a R&D team enjoys such a property as directed self-organization. That means that structures and changes will arise in a research group only when they are already potentially present there. Only when structures are mature enough, control action and social conditions will allow research activities to reach the next, completely new level. Respectively, the scientific policy does not aim to construct any pioneering innovatory scientific organizations from the scratch. Instead, it should aim at activation of 'hidden opportunities' of scientific organization, to enforce its own structures and development path. We can even say that social control of a R&D team is then functioning rationally and reasonably when it is based on natural course of development of a team and does nothing but introduces slight corrections to this natural events instead of arbitrary unconditioned social construction based on some dogma assimilated earlier.

Therefore, systematic record-keeping with respect to internal degrees of freedom of a R&D team, spontaneity and self-organization abilities of the latter imply, first of all, significant correction of goals set for social control over a R&D team. Second, we witness formation of new social and economic feedback mechanisms. More precisely, we are saying that management and control of a R&D should principally be aimed at reaching a "goal attractor". The latter represents both multiple conditions towards which a R&D team is heading asymptomatically in the result of its natural evolution and a management regime desired by the control component. Apart from desired economic, financial and other research procedures, the goal attractor should reflect the scientific essence of a R&D team. The fact that R&D team's own structures and goal attractors are included explicitly in the control and management development procedures provides the team with an opportunity to create a feedback system analytically, both for positive and negative feedback.

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