CONCEPTUAL STRUCTURE OF R&D PRODUCTIVITY ASSESSMENT IN PUBLIC RESEARCH ORGANIZATIONS

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crossref http://dx.doi.org/10.5755/j01.em.19.1.5755

Abstract

In an innovative knowledge society research activities and implementation of its results are becoming one of the most important tasks for universities. In the context of the changing paradigm of university, new structures of research performing organizations emerge along with new problematic aspects of research. Assessment of R&D productivity of a research organization is one of the latter. There is a plethora of scientific literature on the efficiency of business investment into R&D, yet research on R&D productivity or efficiency in public research organizations is still rare. The article aims to construct a conceptual structure for assessing R&D productivity in research institutions. The article defines the concepts of R&D productivity, R&D efficiency and R&D effectiveness; it provides analysis of existing R&D assessment structures or models as well as identifies its advantages and disadvantages. Based on scientific literature analysis, a conceptual structure for R&D productivity assessment in public research organizations was built. Having scientific significance, the structure is also important from a practical point of view as it allows to understand and interpret the R&D productivity and efficiency concept itself, integrating the most important segments of R&D and its surrounding environment. Also, building upon the concept prepared, criteria for R&D productivity assessment can be identified and R&D assessment structure can be constructed.

The type of the article: *Theoretical article.*

Keywords: *R&D productivity; research organizations; R&D environment.*

JEL Classification: *O30, O32.*

1. Introduction

Research problem. Significant globalization, international competitiveness and the development of knowledge-based business gave a new social role for universities. They are expected to produce research activities that ensure tangible benefits for citizens, while application of research and implementation of research results are becoming one of the key goals for science. A rapid increase in the demand for R&D has blossomed research centres of different type and nature: Research Technology Organisations, Technology Transfer Centres, Joint Research Centres, Research and Innovation Centres, Competence Centres and others (all these organizational forms will be referred to in this paper as "research organizations"). There is a plethora of scientific literature on the efficiency of business investment into R&D, yet research on R&D productivity or efficiency in public research organizations is still rare.

Theoretical background. According to Ojanen and Vuola (2003), earlier R&D activities at the firm level were often considered as a 'black box' and an isolated function, which was nearly impossible to be systematically managed and controlled. And while the last decade produced more research on R&D productivity and efficiency, the existing schemes on R&D activities in research organizations (Coccia (2001, 2005), Leitner & Warden (2004), Lin & Bozeman (2006), Cincera, Czarnitzki, & Thorwarth (2008), Paul *et al.* (2010) and etc.) are still missing a cross-cutting, systematic and empirical justification for public bodies. The provided R&D structures do not show the separation between activity assessment in private and public sectors. Insufficient attention is paid to internal and external factors as well as to their impact and assessment.

The purpose and rationale background. *The main purpose of this article is* to compose a conceptual structure for assessing R&D productivity in public research institutions. *Research object* – R&D productivity in research organizations. The paper is structured according to the following research *objectives*:

1) to define the concepts of R&D productivity, R&D efficiency and R&D effectiveness;
2) to present and analyse the existing conceptual structures or models for assessing R&D productivity, and to identify their key limitations and weaknesses;
3) to develop a systematic structure of R&D productivity assessment in research organizations.

2. Method

The paper adopts theoretical research approach, namely comparative and systematic analysis of scientific literature. The first part of the paper is based on Colquhoun, Baines, and Crossley (1993), O'Donnell and Duffy (2005), Paul *et al.* (2010), Bogetoft and Otto (2011), Balezentis and Balezentis (2012) works to present and analyse the concepts of productivity, effectivness and efficiency. The second part provides analysis and comparison of R&D assessment models and strucutures of Coccia (2001, 2005), Leitner and Warden (2004), Lin and Bozeman (2006), Cincera et al (2008), Paul *et al.* (2010) and other; it identifies key components of R&D process in public research organizations and interconnections of such components. The analysis identifies main limitations and weaknesses in structures for R&D effectiveness assessment and justifies the need for developing new R&D structure. The final part presents a systematic structure of R&D assessment in research organization.

3. Results

Conceptualization of R&D productivity

In order to define a concept of R&D productivity, it is necessary, first of all, to understand the essence of R&D and its types. Frascati Manual (2002) defines R&D as systematic creative work of cognition, including the cognition of humans, culture and society, and the exploitation of the newly obtained results. R&D covers three main areas of activity: fundamental research, applied research and experimental development. Fundamental research is carried out primarily to acquire new knowledge about the essence of phenomena and facts that are investigated without any particular application or visualization. Applied research and experimental development, in turn, have a specific practical purpose. These R&D parts are important in evaluating productivity and efficiency of activity in the sense that different types of R&D require different resources, and leads to different processes and, of course, different type of results.

In order to evaluate the results of R&D activities, their role, level or quality, it is important to understand and distinguish the concepts and processes of effectiveness, efficiency and productivity. Productivity is an important factor in economic growth; scientific literature defines and analyses the concept quite extensively and comprehensively. In scientific literature there is no unified definition of these concepts. There are many, even conflicting interpretations of these concepts, but in the most general term productivity is defined as the ration of output to inputs. So productivity means the ability to convert inputs to outputs. The concept of efficiency is an integral part of productivity. Bogetoft and Otto (2011) describes efficiency as a ratio of the observed productivity level to the yardstick productivity level. Effectiveness can be evaluated when certain utility or objective function is defined. Balezentis and Balezentis (2012) note that in the reality, however, this is not the case and in the ideal behaviour can be described only by analyzing the actual data, i.e. by the means of benchmarking. The primary goal of any economic activity is meeting consumer needs. These needs are met by obtaining the maximum benefit with minimum cost. In this way the effectiveness is achieved. However, speaking of research activity, benefits for the consumer is not its primary or

sole purpose, therefore, the analysis and evaluation of both productivity and efficiency slightly differs in the context of R&D activity.

In most general sense, the difference between effectiveness and efficiency concepts can be defined using Activity Model based on IDEF0 as provided by Colquhoun, Baines, and Crossley (1993) (see Figure 1). Efficiency is defined as the difference between output and input i.e., the value created by the activity, divided by the resources consumed in creating the output. Effectiveness is defined as how the output of the activity meets the goal of the activity; is the intended output created (O'Donnell & Duffy, 2005).

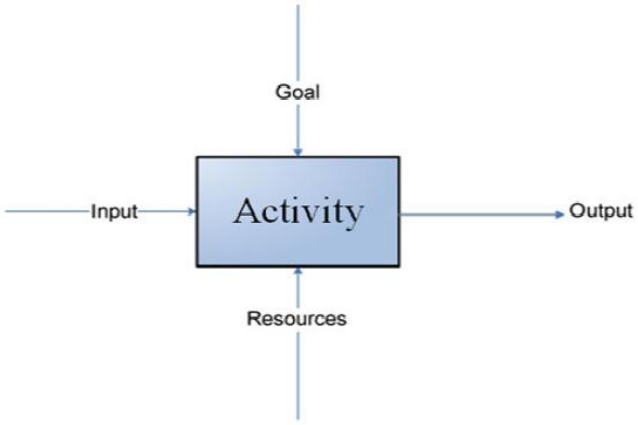

Figure 1. An Activity Model Based on the IDEF0

Source: Colquhoun *et al*, 1993

Thus, according to this model, the R&D efficiency can be defined as its ratio of inputs and outputs. Meanwhile, in order to evaluate R&D effectiveness, it is important to have a certain specified level (objective, norm) which makes it possible to evaluate the degree of achievement or implementation. Different scientific institutions have different visions of the R&D activities or different strategic R&D goals, so their effectiveness evaluation will be different. Most of today's research institutions and research centres seek to commercialize scientific knowledge, i.e. they focus on and move towards applied and experimental development activities, as well as increasing their efficiency and commercial benefit. Etckowitz and Leydesdorff (2000), however, as well note an opposite trend: universities' desire to return to the development of fundamental research activities rather than becoming a commercial subject, and thus the evaluation of effectiveness and efficiency itself as well as its level in research organizations will depend on their R&D strategy, policy or programme they aim to achieve.

Paul *et al.* (2010) introduce the key dimensions of R&D productivity and the goals tied to R&D efficiency and effectiveness (Figure 2). Authors define R&D productivity as the relationship between the created value and the investments required to generate the research process. They elaborate R&D productivity in two dimensions: inputs leading to outputs, or R&D efficiency; and outputs leading to outcomes, or R&D effectiveness.

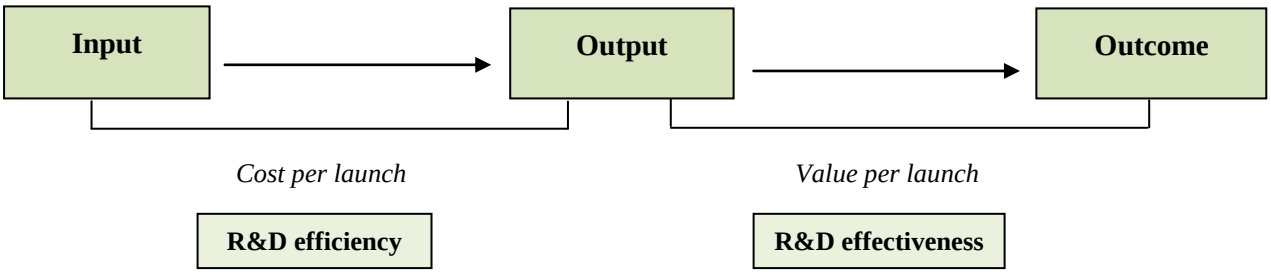

Figure 2. Dimensions of R&D Productivity

Source: Paul *et al*., 2010

An effective R&D productivity strategy must encompass both of these components. R&D efficiency represents the ability of an R&D system to translate inputs (for example, ideas, investments, effort) into defined outputs, generally over a defined period of time. R&D effectiveness can be defined as the ability of the R&D system to produce outputs with certain intended and desired qualities. Thus, R&D productivity can be viewed as an aggregate representation of both the efficiency and effectiveness of discovery and development process (Paul *et al.*, 2010).

The approach to efficiency and effectiveness in this theoretical research is based on findings provided by O'Donnell and Duffy (2005); whereas the goal of a highly productive R&D system, according to Paul *et al.* (2010), is to efficiently translate inputs into the most desired and valuable outputs.

The analysis of R&D productivity assessment structures

This part of the article introduces and analyses the existing conceptual structures and models of existing R&D activity evaluation, allowing to identify the key components of R&D activity process and to describe their interactions. All R&D activity evaluation structures are grouped into four groups according to certain features of structure evaluation, their similarity and elements of novelty.

The first R&D activity assessment structures group is based on input-output ratio evaluation. This group includes the structures provided by such authors as Autio and Laamanen (1995), Sanchez and Perez (2002), Cincera, Czarnitzki, and Thorwarth (2008), Conte, Schweizer, Dierx, and Ilzkotitz (2009), Paul *et al.* (2010). The main axis in these structures is that as introduced by Paul *et al.* (2010) in R&D productivity concept: input-output-outcome. Cincera *et al.* (2008) present similar structure to the above mentioned. In this structure input is divided into monetary and non-monetary resources. The authors distinguish and identify the processes of resource allocation efficiency, technical efficiency and customer-related efficiency. Their structure emphasizes the impact of environmental factors, such as regulatory-competitive framework, socio-economic background, climate, economic development and other, to the level of effectiveness and efficiency. Conte *et al.* (2009) focuses on a public R&D spending and complements the conceptual model by expanding the main components of the model as follows:

- input: public R&D, private R&D spending;
- output: patents (inventive output), publications (scientific output), new product/process (technological output);
- outcome: competitiveness, total factor productivity (TFP) growth, productivity, exports.

Autio and Laamanen (1995) expand these constructs in a slightly different way. The authors distinguish three types of inputs: monetary and physical resource inputs, capability inputs and technology inputs. According to the authors three types of output indicators can be collected research and technology outputs, commercial outputs or monetary and resource outputs.

The second group of conceptual models can be assigned models that clearly identify two different R&D activity processes: R&D development and R&D output spread (transfer or sale). Brown and Svenson (1998) present a model for measuring R&D productivity by categorizing the system to inputs, processing system, outputs, receiving system, outcomes, in-process measurements, output measurements and outcome measurements. Coccia (2001, 2005) adapts and develops the Brown and Svenson's model (see Figure 3).

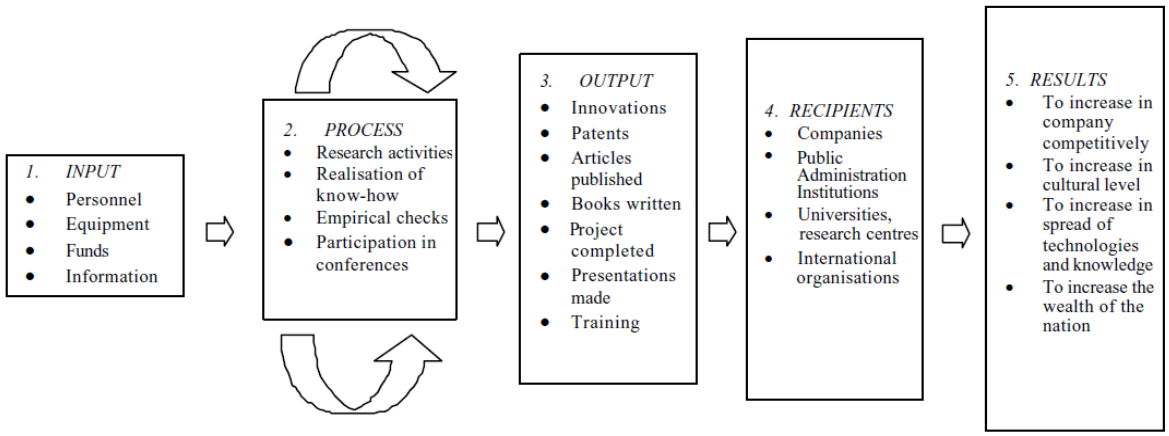

Figure 3. The Production System of the Research Bodies

Source: Coccia, 2001

This conceptual model is applied both for private and public research bodies. The *inputs* are the resources of the system, which generate the cognitive process. They include the human factor, the information, the ideas, the equipment, the libraries, the organizations and the sources of financing. The *production process* of a research body transforms the input into output through the realisation of research projects, training courses, technological service and etc. The *output* of the research laboratories includes the publication of books and reports, projects, software innovations and patents. The *recipient*, who absorbs the output, is different according to whether it is private or public research body. In the case of public research bodies the users are more widespread and include manufacturing industries, public administration bodies, international bodies, professionals and universities. The *results* are also different for private or public bodies. If the users are private this may be profit maximisations or cost minimization, the income, new products, market shares, etc. (Agrell & West, 2001). If the users are public it may be an increase in the cultural level, the solution to social problems, etc. (Coccia, 2001).

Werner and Souder (1997) distinguish two levels of R&D impact:

- macro-level measurement method focus the impact of the R&D on society, as the whole;
- micro-level techniques focus on the impact of a firm's R&D on its own effectiveness.

Ojanen and Vuola (2003) also provide a supplemented version of Brown and Svenson model. The authors complement the old model by showing interconnectedness and dependency of existing concepts of R&D process and pointing out ways of using measurement results in other stages of the process. The authors also add one additional front-end dimension which includes R&D strategy, key goals, competence and other aspects that influence R&D costs and other input.

Like the authors of the latter model, Vijayalakshmi and Iyer (2011) identify input, significant to every research body (manpower, equipment, sophisticated technology and other), the R&D process itself and results (outcome), based on which R&D efficiency is assessed, as the main dimensions of R&D process.

The third group of R&D activity models can be assigned authors that emphasize the importance of intellectual capital to this activity. Lin and Bozeman (2006) (see Figure 4) pay more attention both to organization's internal environment processes and competences of a scientist. The authors focus on the scientist's competences, i.e. his knowledge, skills and especially his previous experience. Figure 4 recognizes that the scientist depends critically upon others resources, scientific contributions, but the model's orientation is chiefly internal (Lin & Bozeman, 2006). According to the authors, this is a functional model for the creation of discrete knowledge products but has few if any direct implications for the sustained capacity to create knowledge products and build fields of science and technology development.

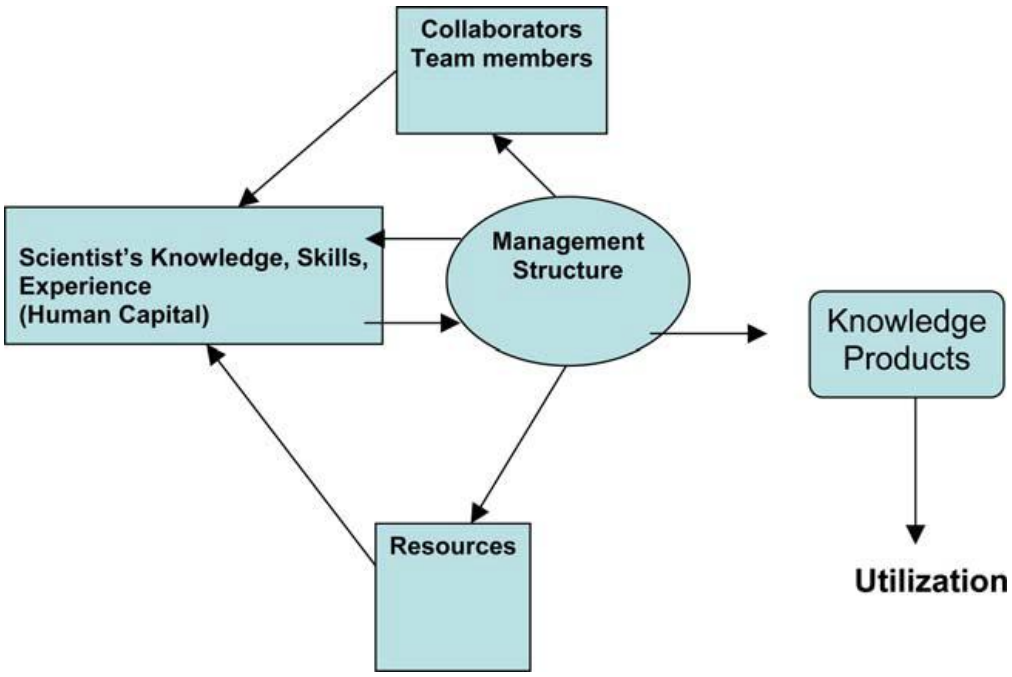

Figure 4. An Output Model for Assessing Center Researchers' Productivity
Source: Lin & Bozeman, 2006

Leitner and Warden (2004) IC model for research organizations also analyze the concept of IC and its significance in the R&D process (see Figure 5).

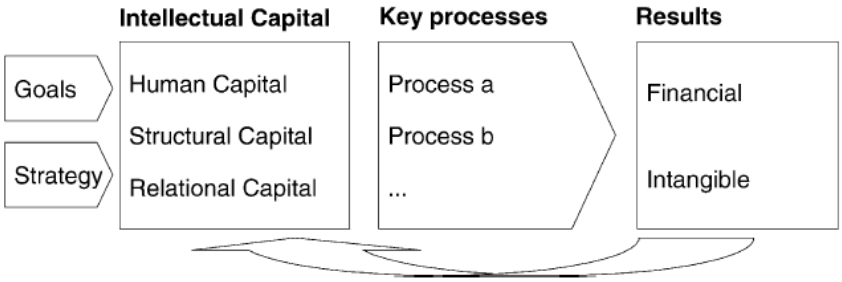

Figure 5. Basic IC Model for Research Organisations
Source: Leitner & Warden, 2004

The authors describe the specifics of IC management and reporting in research organisations and in particular the question of its impact on the production process and on their organisational performance. Model explicitly separates inputs, processes and outputs. The logic of the model combines goals, intellectual capital, organisational processes and results. The authors regards IC as intangible resources. It is composed of structural, human and relational capital. The model analyses R&D process depending on the R&D type. According to the authors, the R&D processes are clearly different kinds depending on the research activities, such as basic research, applied research, contract research projects, services or teaching. The outputs of these different kinds of projects are various kinds of Results. The model distinguishes two types of results: financial and intangible. Authors note that the outputs of a research organisation are often public goods and therefore not all outputs are sold commercially so that a price can be derived for a financial valuation. Intangible results are refined in economy (industry), research and society oriented results.

The fourth group pf R&D activity structures can be assigned models with a significant focus on the performance goals and, of course, on the assessment of achieving these goals. Griffin and

Page (1996) categorize the project-level measures to customer-based success, financial success, and technical performance success. They suggest that assessment methods and indicators should be chosen depending on the innovativeness of the project or company's strategy, and distinguish three possible strategic conditions. R&D efficiency here is assessed through the perspective of private company investing into R&D activities for improving certain products. However, the assessment approach itself, i.e. the distinction of three levels based on innovativeness of company's or organization's strategy can be significant both to private and research organization. The constructs of strategy and objectives are also emphasized in Ojanen and Vuola (2003) and Leitner and Warden (2004) models as indicated above.

Justification of the need to develop an integrated R&D productivity assessment model

The analysis of conceptual structures for activity assessment in research centres showed that there is no single integrated model that includes all main R&D processes and elements of this process, and shows their connections. In order to assess the productivity of R&D activities, researchers use different components of productivity, effectiveness and efficiency, and analyze them differently. The structures introduced have the following limitations:

- At the beginning of this article R&D concept and its main types were presented, taking into account that different types of R&D activity require different resources and lead to different results. However, the only conceptual model that analyze R&D activity according to different types is that by Leitner and Warden (2004).
- In knowledge development process intelectual capital plays one of the key roles. Therefore, a scientists is exceptionally important in R&D activity. However, only two models, namely those by Leitner and Warden (2004) and Lin and Bozeman (2006), note and analyse the significance of intelectual capital in the assessment of R&D process.
- To fully realize the internal scientific potential of a scientist, certain organizational conditions must be ensured. The main shortfall of the analyzed conceptual models of R&D productivity assessment is insufficient attention to organization's internal and external environment and its assessment. Precisely these factors often determine both the level of results and the depth of their application. R&D activities are developed in constantly changing, dynamic external environment and are strongly dependent on it. Assessment of external environment factors is extremely important in developing market economies, including Lithuania. Etzkowitz and Leydesdorff's Triple Helix model (2000) suggests that a lot of centralized control elements remained in these countries that prevent effective R&D activities. Poorly developed R&D infrastructure and low scientific production have significant impact on R&D activity efficiency.
- All activities must have their objectives in order to evaluate the degree of implementation and to identify performance effectiveness. Therefore, objectives are also highly important in R&D activity as they indicate the principal direction and determine the assessment. However, the models by Griffin and Page (1996), Ojanen and Vuola (2003) and Leitner and Warden (2004) distinguish the components of objectives and strategies that influence the system of R&D activity.

The analysis of conceptual models of R&D productivity assessment in research centres showed that there is no unified integrated structure that includes main activity processes which would identify and elaborate the main components which need to be assessed.

Construction of conceptual structure of R&D productivity assessment in research organization

Summarizing the analyzed structures and models of R&D productivity assessment, their characteristics and shortfalls, an integrated structure of R&D productivity assessment in research organizations was constructed (see Figure 6).

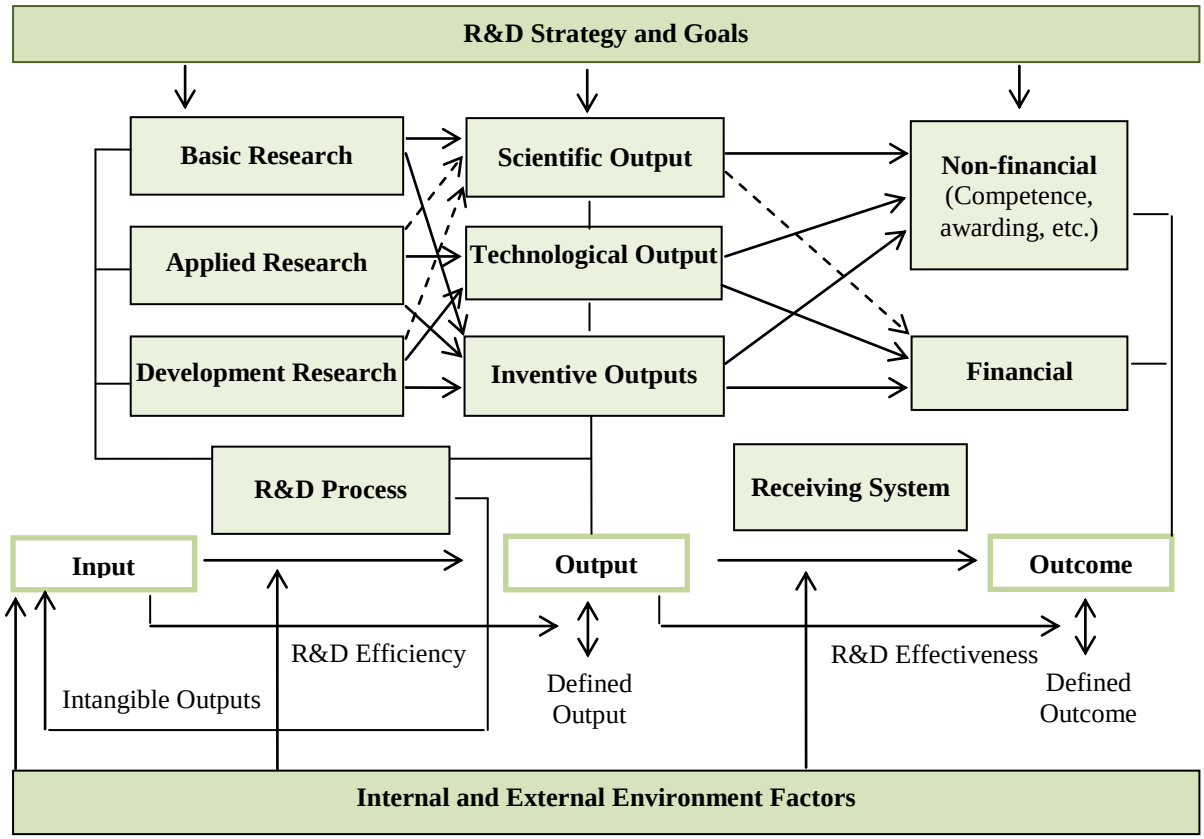

Figure 6. Conceptual Structure of R&D Productivity Assessment in Research Organizations

Scientific literature analysis revelead that usually in R&D productivity concepts three main components are distinguished: inputs, outputs and outcomes. Thus, it can be assumed that this sequence is the basis of R&D productivity concept which devides the system into two different processes: R&D process and receiving system. Inputs can include ideas, information, people, effort, investments, equipment, requests, funds needed for activities, etc. Inputs are the resources of the system, which generate the cognitive process. The process of producing scientific activity is divided into three main activities according to the R&D types, namely fundamental research, applied research and experimental development, because different R&D type requires different financial, time and other resources, and produce different types of outputs. Outputs can include publications, new products or processes, knowledge, patents, etc. They can be divided into three main categories: scientific outputs, technological outputs and inventive outputs. Not all outputs determine outcomes because not all R&D activities are carried out with a practical purpose. In the case of fundamental research, the activity is generally directed into deeper assimilation of new knowledge rather than on application of knowledge in a short-run. Also, some of the R&D projects fail and cannot provide useful results. However, it does not make R&D productivity less significant and the need of its assessment is not diminished. The formulated structure distinguish intangible outputs, i.e. a tangible product is not created, only scientific knowledge and experience is deepened, therefore, the figure shows its connection to input as the increase of human resource competence.

In most general sense, two main directions of R&D benefits can be identified: a benefit for organizational unit which carries out R&D or invests in R&D activity, and a benefit for environment. This study assesses productivity from the perspective of research organization, therefore to types of outcome are distinguished: financial and non-financial, i.e. results, which a research organization obtains after transferring its scientific production, are assessed.

Just like any other activity, R&D takes place in a certain social and cultural environment which has a direct influence on employees' well-being, motivation, resources and similar, thus the

assessment of both internal and external environment becomes a significant aspect of R&D productivity.

Analysing productivity of R&D or innovative activity, a special attention is paid to productivity of persons that carry out intellectual work because scientist is the main capital in this activity. Research carried out by Stripeikis and Ramanauskas (2011) prove that personnel skills and their personal preferences are extremely important to R&D productivity. Therefore, not only the choice of employees becomes an important aspect but also the empowerment and development of their personal and scientific potential. For employees' internal potential to be fully harnessed, certain organizational conditions must be secured: organizational environment must motivate and promote active work, helping to reveal the inner potential of employees. Properly designed organizational environment promotes employees' positive approach to work, increases their self-esteem, self-confidence, loyalty, responsibility and performance. Therefore, in the introduced assessment structure internal and external environment of R&D activity and its factors become a very important component of the system. Scientific activity results and its efficiency depend not only on scientific and technical potential of organization, but also on external environment factors, such as political, economic, social-cultural or technological environment. Studies that analyze the assessment of environment favourability to R&D activity are still very rare. Wieser (2005) argues that different R&D results are determined by systematic differences berween countries or industries and different means of political support for R&D. Authors that analze R&D productivity and the difference and amiguity of its results only point out to the possibile impact of different R&D activity environment on efficiency but do not engage into further analysis.

The R&D productivity assessment structure provided in this article includes both R&D efficiency and R&D effectiveness assessment dimensions. In order to evaluate R&D efficiency or R&D effectiveness, a desired level of production or results must be emphasized. Efficiency then can be the amount of scientific production during a certain period of time, or the amount of scientific production per scientist. This and other ways can be used to assess and analyse the efficiency of the use of intellectual capital, resource allocation and technical efficiency. Research organizations differ in their ownership structures, legal status, organisational structures, so it is only obvious that they will have different missions and outputs. It shows that assessment of effectiveness and its level in different research organizations will depend upon the type and structure of an organization, its R&D strategy and major objectives. The main estimate of research organization's effectiveness can become, for example, a financial index given that the main objective of the organizations is commercialization of scientific production. So the emphasis of different factors or dimensions in the constructed model set different requirements for the evaluation criteria in the final selection of R&D performance measures.

4. Discussion

The conceptual structure for R&D productivity assessment was constructed based on systematic approach as R&D productivity is conditioned by both R&D activity mechanisms within organizations and its connection to external environment. These processes compose and include R&D activity system which can be defined as an aggregate of elements and interacting mechanisms which create preconditions for efficient R&D activity and full use of scientific potential. The constructed conceptual structure for R&D productivity assessment in research organizations is both scientifically and practically significant allowing to understand and interpret the concept of R&D productivity and efficiency and its entire operating system. The structure includes the main segments of R&D activity and its surrounding environment and shows their interconnections:

- the distinction between two main R&D activity processes is maid: R&D process and receiving system;
- the process of obtaining scientific knowledge is explained in detail according to R&D types;

- R&D production is divided into three groups of tangible outputs, the relation with two types of outcomes is identified; the component of intangible outputs is emphasized;
- elements of R&D efficiency and R&D effectiveness are identified and the necessity of defined output and results for assessment is shown;
- elements of internal and external environment are distinguished and the necessity of their assessment is emphasized.

The constructed approach of R&D assessment can be of value for:

- R&D performance and perspectives analysis;
- formulating R&D policy of a research organization, identifying strategic R&D objectives;
- constructing assessment model of R&D productivity;
- defining the purpose, level, type or method of R&D performance measurement;
- identifying assessment criteria of R&D productivity.

The constructed conceptual structure of R&D productivity assessment in research organizations allows to understand and interpret the aggregate of R&D productivity and efficiency concept, it integrates the most important segments of R&D activity and its surrounding environment and shows the connections among them. Based on this structure the criteria for R&D productivity assessment can be identified or R&D productivity assessment model in public organizations can be constructed.

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