The R&D Indicators in the Knowledge-Based Economy: The Research Paradox

Asterios CHATZIPARADEISIS
Ministry of Development
Greece
asteri1@hol.gr

Abstract

Out of all R&D indicators, the older yet more preferred one is the Gross Domestic Expenditure on R&D (GERD) most of the times expressed by the "r" indicator, i.e. the percentage of GERD on Gross Domestic Product (GDP). In this paper we prove that the capacity of the GERD or *r* indicator to convey in a reliable way the actual evolution of the R&D sector and of the economy in general, is limited. Indeed, a variety of contradictions have been observed between the aforementioned indicators, which we will henceforth refer to as the "Research Paradox". The paper makes recommendations for improving the selection and usage of existing R&D indicators as well as proposes alternative measurements while in the Knowledge-Based Economy (KBE).

Measuring Research & Development

The aim of Scientific Research is the generation of new scientific knowledge as well as the correction and integration of previous knowledge, either immediately applicable or not. The roots of scientific research can be traced as far back as the ancient times, boomed during the renaissance period but the massive and systematic engagement in Research and Development (R&D) activities, not only in Academia but also in Enterprises, is only a recent phenomenon of the 20th century.

The importance of R&D in the 20th century resulted to a respective need for measurements and indicators[1]. During the 1930s the first measurements of R&D indicators took place in the USA to account for the need of managing industrial laboratories and the respective planning of scientific activities. Canada followed one decade later, while the UK took some additional ten years to carry out such activities. The massive financing of R&D by national governments and enterprises of other developed countries after World War II, generated the need for measurements of similar indicators in those countries as well.

During the early 1960s, OECD undertook a leading role and coordinated the work of measuring R&D performance mainly by developing the first methodological manual for the collection of R&D data, which is known as the Frascati Manual[2]. The Frascati Manual, the first edition of which was issued in the beginning of the '60s, was focusing mainly on two input indicators of R&D investments: the *Financial Resources* spent for R&D activities and the *Human Resources* invested in R&D activities. The measurements covered four sectors: the sector of Government, which included the government research laboratories, the sector of Enterprises, the sector of Higher Education and the sector of Private Non-Profit Organizations. The measurements were focused on institutions rather than individuals.

During late '80s and early '90s additional manuals were created by OECD and EUROSTAT on impact indicators, e.g. the *Technology Balance of Payments*[3] (TBP), on output indicators, e.g. the *Oslo*

[1] Benoit Godin, The Number Makers: A Short History of International Science and Technology Statistics, Project on the History and Sociology of S&T Statistics, Working paper No. 9, 2001.
[2] La mesure des activités scientifiques et techniques. Méthode type proposée pour les enquêtes sur la recherche et le développement expérimental "Manuel de Frascati" OECD 1980.
[3] Technology Balance of Payments "TBP" Manual, OECD

Manual for Innovation[4], as well as on a broader spectrum of subjects such as the *Canberra Manual for the Human Resources for Science and Technology*[5].

Out of all R&D indicators, the older yet more preferred one is the GERD and the *r* indicator[6]. Since the '60s when the collection of R&D data started in the OECD countries, this organization has developed various analyses and studies based on GERD or *r*. The countries were grouped in categories such as "big", "intermediate" and "small", according to the size of their GERD, or "high-", "intermediate-" and "low-R&D intensity" according to the r indicator.

The use of these indicators was diffused rapidly. Through several analyses and categorizations, the positive relation between GERD and economic growth of the countries was supported, e.g. in the USA with an *r* at the level of 3% since the beginning of the '60s, was considered to be a good example that others should follow.

The importance attributed to GERD continues to be very high even today. In the EU this indicator constitutes one of the central indicators of the Lisbon Strategy; one of the main objectives being the rise of this indicator across EU members from an average of 1,9% in 2000 to 3% of the EU GDP up to 2010.

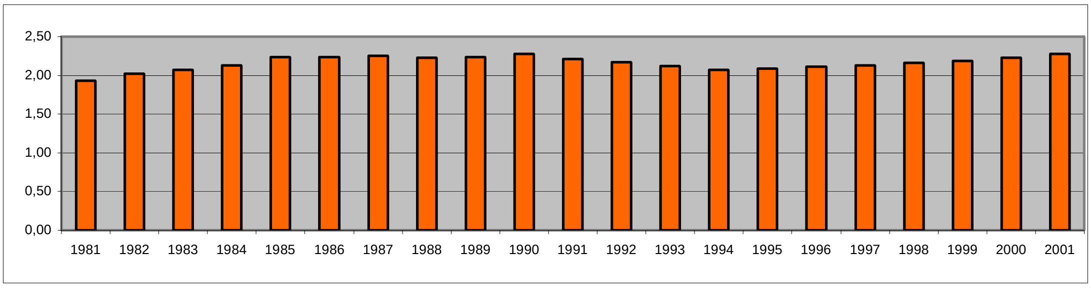
Furthermore, in a relatively recent survey of the OECD[7] it was presented that GERD and *r*, continues to be the most popular indicators. More than 80% of the countries value it very high in their preference list, while other indicators like Patents, the Technological Balance of Payments, and the Trade of High Technology are preferred by less than 50%.

The Research Paradox

The ability of the GERD or the *r* indicators to express in a reliable way the actual growth of R&D and of the economy in general, is in our opinion limited. A variety of contradictions have been observed in the application of the aforementioned indicators, which we will henceforth refer to as "Research Paradox".

In Figure 1, the evolution of the *r* indicator is presented for the total of the OECD countries during the time period 1981 - 2001[8]. The histogram reflects what seems to be a remarkable stagnation, which does not keep up with the revolutionary developments that happened during this period. Indeed, from 1,93% of GDP in 1981 it rose to just 2,28% in 2001, and not even in a linear way but by exhibiting fluctuation during that period.

Figure 1: Percentage of R&D Expenditure to GDP in OECD Countries



If we examine the EU-15 or the USA independently, during the same period, the picture is not very different. The indicator rose from 1,67% to 1,92% in the EU-15 and from 2,34% to 2,73% in the

---

4 Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data, 3rd Edition. OECD, Paris 2005

5 Manual on the Measurement of Human Resources devoted to S&T "Canberra Manual" OECD, Paris 1995

6 Benoit Godin, The Most Cherished Indicator: Gross Domestic Expenditure on R&D Project on the History and Sociology of S&T Statistics. Working Paper No. 22.

7 OECD (1998), How to improve the MSTI: First Suggestions From Users, DSTI / EAS / STP / NESTI / RD (98)9

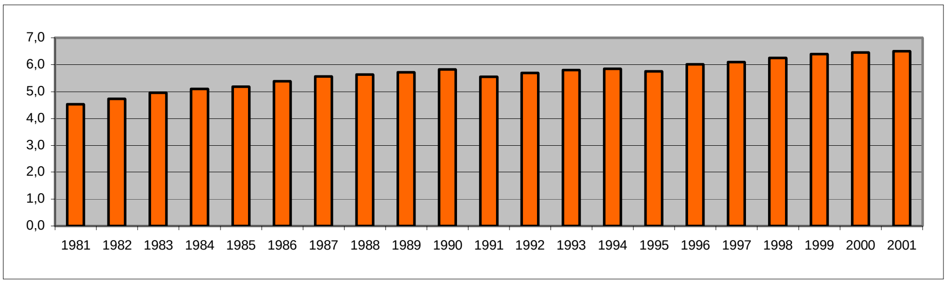
8 OECD, Main Science and Technology Indicators

USA. In the USA the same indicator was at the level of 2,6% in 1959 and at 2,8% in 1962. Thus USA's *r* indicator has been hovering at the same level during the last four decades.

The stagnation of the *r* indicator shows that the growth of GERD in absolute values is approximately at the levels of the growth of the GDP for this period i.e. at the level of 3-5% annually. By examining the above figures, one would say that the promotion of R&D and the production of knowledge didn't constitute an important priority of national governments and enterprises during the last 20 years, at least not at the level for it to increase at a higher rate than GDP.

If we study other important input indicators for the same period, like the number of *researchers per 1,000 workers*, we observe that it presents almost the same stagnation (Figure 2): the number of researchers per 1000 workers rose from 4,5/1000 researchers in 1981 to 6,5/1000 researchers in 2001.

Figure 2: Number of Researchers per thousand employees (OECD countries)



On the other hand, if we study output indicators, the picture is totally different: the number of new products increased heavily, the life-cycle of the products shrank intensely, technologies are getting obsolete rapidly, etc. Unfortunately there is no data available on the number of innovations in order to quantify the rapidly rise of this indicator. The number of patents constitutes a proxy of production of innovations as only a part of innovations is patented. Still, despite the partial coverage of innovation by the patents indicator, this indicator presents a growth obviously bigger than that of input indicators. For example, the number of patents registered in the European Patent Office (EPO) by the OECD countries increased by 272% during 1981 - 2001, while the number of patents registered in the US Patent Office (USPTO) increased by 157%. In the knowledge intensity sectors the rise is even bigger. Furthermore, in the same period the patents in the sectors of Information and Communication Technologies (ICTs) presented a rise of 470% and in Biotechnology 805%.

The Old (Industrial) and the New (Knowledge) Economy

In order to interpret this "Research Paradox" (i.e. stagnation in R&D indicators compared to an explosion in the production of knowledge and innovations) we need to look deeper into the changes that came about with the New Knowledge Economy.

The main characteristics of the "old" Industrial Economy are the following: Almost the entire generation of knowledge took place in Research Laboratories (RLs), those had almost exclusive access to the knowledge infrastructure (libraries, laboratories, other supervisory instruments etc.) while the rest of the human capital was relatively alienated from this, they were also staffed with human capital that had the required skills and capacities for scientific developments (e.g. people with postgraduate titles and doctorates), and continuous learning processes were implemented. In the enterprises, on the other hand, human capital were in high percentages either semiskilled or even unskilled workers. Furthermore, the life cycle of the products was comparatively big, the Economy was supply-driven and innovation was periodical and linear[9].

---

[9] Anthony Arundel, Wendy Hansen, Rene Kemp, State of the Art of the Knowledge-Based Economy, report prepared for Knowledge Economy Indicators: Development of Innovative and Reliable Indicator Systems (ref. WP1.1, KEI project), DG Research, 2006.

The catalyst that caused the rapid changes in research but also in the entire economy was the very rapid development and diffusion of the Information and Communication Technologies (ICTs). The heavy rise of the processing power of the computers (doubling every 18 months – Moore's Law) contributed a lot to the improvement of the quality of the performed R&D. The penetration of the Internet promoted the exchange of ideas between research teams in different geographic areas, thus improving further the quality of R&D through collaborations. Still the big revolution was the implementation and wide-scale adoption of the World Wide Web (WWW).

The creation and very rapid spread of the Web were the catalyst that crumbled the walls and permitted the diffusion of the information and the knowledge to the whole population. Through the Web an enormous volume of data, information and knowledge became available to everyone accessing the Internet. As such, the access to information and knowledge has evolved from being a "privilege" to being a "right", of everyone instead of only people working in research departments.

Each worker, each citizen having a PC connected to the Web, has access to a volume of knowledge inconceivable in the previous decade(s). Therefore each scientist has the possibility to reorganize and treat the existing knowledge and produce new knowledge. *In the New Economy each and every scientist can be a potential researcher and inventor.*

Briefly the following are other related changes which happened in the New Knowledge-based Economy:

- in big enterprises the production of knowledge does not emanate exclusively from the R&D departments and the researchers but, depending on the sector and the firm, an important part of the scientific staff of the firm participates in this. The departments of production, marketing, etc. are particularly active in the generation of information and knowledge for new products. For the organizational innovations, a significant role is assumed not only by the product departments but also by the general administration of the firm.
- the rapid development of the technology intensified the training processes of the personnel of enterprises and created learning mechanisms for the majority -if not for all- of the staff. Many scientists name the current economy as "Learning Economy".
- the education level of the employed human capital is nowadays considerably higher. The working personnel of enterprises comprise of many more workers with University, post-university and doctorate degrees, compared to the past. This personnel is familiar with research and generation of new knowledge, since it has invested significant time in such activities, and it is capable of generating new knowledge, despite working outside R&D departments.
- the innovation model has changed from a "linear" to an "interactive" one. The development of new products in the modern enterprise is a complicated process consisting of a lot of stages in which many departments of the firm participate by contributing knowledge and information[10].
- the goods produced by enterprises become increasingly "individualised" and oriented towards the needs of the customer. In the previous model, the supply determined to a large extent the demand and the products had a big degree of standardisation determined generally by the R&D department. The new model is customer-driven.
- the life cycle of the products has become very short.
- innovation becomes the basic objective of all enterprises, not only of the manufacturing ones but also of those in the services sector. There is consequently production of knowledge in the services enterprises, which is inadequately measured or not measured at all.
- new forms of R&D are carried out such as the "distributed research" (research in network) which is hardly measured in its wholeness by the surveys

[10] Komninos N. (2002) Intelligent Cities: Innovation, knowledge systems and digital spaces, London and New York, Spon Press

What to measure in the Knowledge-Based Economy

It can be therefore entailed that the existing methodology for the measurement of R&D captures only a small part of the activity and consequently the indicators are significantly underestimated. It is believed that the knowledge-generating people are many more than the counted since the existing measurement system records as such only those officially declared as “researchers”.

This discrepancy between the values of R&D indicators and reality should be investigated in the changes that took place in the research system and in the weakness of the measurement system to adapt and measure adequately the new situation.

The methodology of the Frascati Manual for the measurement of R&D was created in the beginning of the '60s and was influenced by work previously done in the USA, as adapted in the conditions of that period. It is well-known that it is difficult to come up with an all-inclusive and pin-pointed definition of research and separating the R&D activities from other scientific and technical activities is far from being an easy task. For the data-collecting surveys on R&D, it is mandatory to clearly define a unit that will ensure the continuity and cohesion of the measurements.

In the decades of the '60s, ‘70s and '80s, new knowledge was produced mainly in Research Laboratories belonging to a University, Research Center or Private Enterprise. Consequently the focus of measurements in these institutions had given a satisfactory measure of the countries’ effort for the production of new knowledge. The R&D outside the system was not included in the measurements since it was not important in volume.

This methodology significantly underestimated for example, the R&D performed by the Small and Medium-sized Enterprises (SME’s). The R&D activities of the SMEs are generally mixed up with other activities of the enterprise since the SMEs very rarely have personnel exclusively dedicated to the R&D activities. As it is not easy to isolate the total research effort of SMEs, there is an underestimation of the indicators. Kleinknecht[11] conducted an assessment of the R&D measurements produced by the official surveys for the enterprises. He carried out a survey and found out that the number of man-months of R&D in SMEs were four times bigger than the one reported in the official statistics. The underestimation of R&D in SMEs in official surveys was globally about at the level of 33%. This underestimation should be even bigger today since the personnel of SMEs is much more active in innovation.

All this scattered production of knowledge, which is very difficult to be measured with satisfactory precision, has very serious impact on the economy. It is used in the processes of decision-making, problem-solving, creation of new products, processes, services etc. A great part of this new knowledge is coded and presented in various web sites or portals and contributes to further diffusion and production of knowledge.

If we consider the R&D conducted by the research laboratories as "formal" and the R&D outside the laboratories as "informal", it becomes obvious that the volume of informal R&D has increased rapidly due to the reasons that were mentioned above. Although effort is being put in the last edition of the Frascati Manual[12] to measure the informal R&D, this is still being measured inadequately and is thus the reason why we continue to observe this stagnation of the indicators. Several knowledge-intensive enterprises such as Microsoft and Nokia, have adapted their measurements to the new approach, and their indicators reflect now more accurately the generation of knowledge. For this reason, they exhibit very high percentages for R&D expenditure and personnel compared to other companies, e.g. Nokia Finland states that research personnel accounts for the 1/3 of its total personnel.

If we want to correct to some extent the Research Paradox for the examined period 1981-2001 we should measure and add the "informal" R&D as well. There are also other adjustments that could be applied on R&D expenditure in order to bring it closer to reality. These adjustments could be the use of e.g. “hedonic prices”, since a lot of goods used in R&D (e.g. computers, electronic equipment,

---

[11] A. Kleinknecht (1987) Measuring R&D in Small Firms: How Much Are We Missing?, The Journal of Industrial Economics

[12] Frascati Manual, Proposed Standard Practice for Surveys on Research and Experimental Development. OECD 2002

communications, new materials etc) present enormous improvement in their performance while their prices remain at the same levels or are even decreasing.

Still, these adjustments would not resolve completely the problem which seems to be of structural nature.

The measurement of R&D, as it is described in the methodology of the Frascati Manual, is linked to material economy and particularly to Manufacturing. For that reason the Manufacturing sectors have concentrated the bigger percentage of the measured R&D. We have to have in mind that, before WWII, services were considered as a sector that did not contribute to the development of a country. During 1930s when the GDP indicator and its application was refined in the USA, it was even assumed that services should not be included in the GDP because they do not produce wealth! According to this point of view it was expected that the measurements of R&D, which began around the same period in the USA, included only the Manufacturing sector. As stated also in the last edition of the FM, "The basic definitions in this Manual were originally developed for manufacturing industry and research in the natural sciences and engineering". In the last editions of the Manual an effort has been put to cover also activities such as software development, certain branches of services, social sciences etc. but the results are not encouraging since the way of measurement continues to be the research laboratory which is not typical of the firms in the services sector.

The same phenomenon is also observed in the measurements of Innovation. The methodology of the Community Innovation Surveys (CIS) seems to work well for manufacturing but not for the services[13].

It is already realizable that the Manufacturing sector shrinks and we are moving rapidly towards a services economy. Consequently the measurements of R&D will continue to present more and more ambiguities and underestimations.

In the Knowledge Based Economy the most important good is **Knowledge**. Therefore the effort should be oriented towards the measurement and the management of knowledge.

The high importance attributed to knowledge is being verified also by the fact that enterprises are moving to the direction of organizing seminars on the management of knowledge rather than on R&D or technology. International organizations (OECD, EU etc), universities, research institutions etc organize seminars and conferences on the comprehension of mechanisms and processes that affect the creation, organization, interaction of knowledge with the ICTs, the entrepreneurship, the economy and the society. Recent examples are the organization by OECD, EU and NSF of an international conference on "Advancing Knowledge and the Knowledge Economy", the Conference "Knowledge Economy – Challenges for Measurement" by Eurostat etc.

During the last decade OECD organized important events covering the subjects of policymaking and the measurements as well. Since 1996 in the frame of the "Blue Sky Project" a "Conference on New Indicators for the Knowledge - Based Economy" was organized. Working Groups were created which produced several papers and reports. Many results were incorporated in a series of publications on policies called "Science Technology Industry Scoreboard".

The approach of OECD produced useful results and concepts but from the "Scoreboard" publications one can conclude that the KBE was used simply as a label. Under the same umbrella a series of well known indicators are gathered which are either already measured for decades or are variants of old ones and are nowadays included as KBE indicators[14].

Knowledge is a non-material and hardly definable concept, therefore its measurement is obviously a difficult task. F. Gault states that «Measuring knowledge itself is more challenging, if not impossible. There is no unit of knowledge that corresponds to a currency unit in the System of National Accounts and there is nothing comparable to concepts of current and constant currency units which support comparisons of the economic system over time. There is also nothing comparable to purchasing power parities (PPP) that support comparisons across space».

---

[13] Keith SMITH, The Oxford Handbook of Innovation, Chapter 6, "Measuring Innovation" page 169 Edited by Jan FAGERBERG, David C. MOWERY and Richard R. NELSON, OXFORD University Press, 2005

[14] F. Gault - Measuring Knowledge and its Economic Effects: the Role of Official Statistics, in Conference Advancing Knowledge and the Knowledge Economy Conference, January 2005

The above shows how difficult it is to work under the narrow viewpoint of financial measurements. KBE should however be considered with broad mind and we not be limited to the measurements in some sectors which are directly related to the KBE; instead, we have to adopt innovative approaches.

Obviously it is very challenging to formulate definitive proposals and solutions for the measurements and the indicators of the KBE. The following are some initial thoughts on the direction to which further work could be oriented:

A new **Manual for Knowledge** is needed. The production of knowledge, its diffusion, transfer, acquisition, absorption-assimilation, its use in generating added value, are all important parameters that should be measured.

The fundamental task here is the definition of the concept of **knowledge** as accurately as possible. A second task closely related to the first one is its discrimination in **categories**. Nowadays, for reasons of tradition and facility, the measurements for the new knowledge are very restrictive. The R&D expenditure is considered as the expenditure for the production of new knowledge while the articles published in reviews used by Science Citation Index (SCI) are considered as outputs.

Undoubtedly these two indicators represent the production of core knowledge. The insufficiencies in the measurements of R&D were already reported above. Regarding publications, the articles in reviews of the SCI should not be considered as the unique source of knowledge; on the contrary, working papers, theses for post-graduate studies, articles in technical reviews, all contribute substantially in the production of new knowledge. This contribution is of different type but equally useful in the generation of new products and services. Thousands of articles and documents are uploaded every day in the Web. Although they lack the high quality of those published in scientific reviews they still provide precious knowledge to scientists, company executives, and everyone else all over the world.

An accurate and functional categorization of knowledge is a basic condition for the comprehension of KBE. The existing categorizations of knowledge as "codified" and "tacit", productive and theoretical etc. can be a starting point for the creation of new concepts and categories. The measurement of codified knowledge, which spreads with outstanding intensity, could give a measure of the advantages that the KBE provides to the scientist and the executive of the enterprise.

The **Flows** of knowledge are a very important parameter. Measurements so far are limited to the easily recognizable cases: the co-publication of articles, the purchasing by the enterprises of R&D services produced by the Universities, the purchasing of patents etc. Yet, important flowing of knowledge exists also in the collaborations between research institutions and enterprises without purchasing of R&D services as is the case of e.g. the EU Framework Programs or the national programs for the promotion of R&D.

Unprecedented flows of knowledge are created through Internet and the World Wide Web. Unfortunately statistics for the Internet, besides the elementary ones, actually do not exist and this is a very big disadvantage. KBE is the "child" of the ICTs, the Internet and the World Wide Web and the lack of measurements for the Internet is a huge obstacle for the comprehension of the KBE.

The **Absorption** and assimilation of knowledge from **human capital** is another important parameter. The indicators of formal education give a picture which is quite different from reality. As an example, the indicators on educational degrees reflect the situation at the moment of the acquisition of the degree. The deeper this moment lies in the past the more dramatically this snapshot changes whatsoever. The histogram of specializations as it is given by the surveys on diplomas of human potential is very different than the one that corresponds to the real employment of this potential.

The **Training** of the human resources, which leads to new specializations and skills, plays a very important role. The existing indicators for the training are few and very general (number of individuals that had a training, hours of training etc). Without an official system of **certified training** from which specific qualifications and skills are "produced" it is difficult to measure the actual level and the specialization of the human potential of an enterprise or country at a given moment.

The **Utilisation** of knowledge is one of the most important indicators. **Innovation** lies at the heart of the KBE and constitutes the most important economic output. The surveys on innovation began as measurements of the output of the R&D but then changed to measurements of activities. B. Godin's statement is eloquent[15] “The recent internationalization of innovation surveys was characterized by a conceptual shift from outputs in the 1979s to activities in the 1990s. Without really noticing that they had departed from their original goal, national governments and the OECD ended up measuring innovation the way they measured R&D, i.e.: in term of inputs and activities”. The surveys on innovation should therefore become again measurement of outputs.

The spread of innovation beyond the technological, market and organizational level that has been included in the last revision of the Oslo Manual is towards the right direction. The surveys should cover not only the business sector but also the rest of the sectors of the economic activity.

Finally innovation should be more connected to the production, assimilation and use of knowledge than to R&D. From this point of view the **management of knowledge** should be studied in relation with the promotion of innovation and knowledge inside the firm or the organization. An initial effort[16] has been put into this but more should be done in a more innovative way.

Conclusions

The description and measurement of the New Economic Paradigm is not possible using the concepts, tools and measurements of the old one.

The shifting of the center of gravity from the Manufacturing to the Services sectors, from the Material Economy to the Immaterial and the Knowledge Based Economy, stipulate also the need of upgrading our measurements and indicators: R&D indicators were the appropriate measurement for Manufacturing but hardly anymore for the KBE. Instead, the measurements should be directed to the more important element of KBE: *knowledge*. The production, distribution, transfer, acquisition, absorption – assimilation, use etc. of knowledge are variables which should interest both the researchers and the policy makers.

KBE is a phenomenon produced by the development and diffusion of the ICTs, the Internet and the World Wide Web. These elements therefore lie in the core of the new system, through which the generation and distribution of the bigger part of information and knowledge is accomplished. As such, coming up with data and indicators for the Internet and the Web is an imperative step, not only for comprehending the revolutionary phenomena of the KBE but also for quantifying its effect and designing future roadmaps.

New tools are needed, which will not be a simple modification or adaptation of the old ones. The gathering of old, known indicators under a new umbrella does not constitute a solution and it does not promote the comprehension of the new system whatsoever. As it has been already stated, adoption of innovative approaches is needed.

KBE is a new reality, which is still in evolution and its characteristics are not yet crystallized. More economic research, pilot studies and surveys are needed as well in order to reveal the main characteristics of the New Economic Paradigm and help the policy makers in their work.

[15] Benoit Godin “The Rise of Innovation Surveys: Measuring a Fuzzy Concept”, Project on the History and Sociology of S&T Statistics. Working Paper No. 16, 2002

[16] Knowledge Management, Measuring Knowledge Managements in the Business Sector, First Steps. OECD and Minister of Industry, Canada 2003