Impact of technological innovations on economic growth of nations

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ABSTRACT

The aim of this paper is to review current achievements relating to the theory of innovative activity and innovation including concept of 'triple helix' and its extension by adding customer. A concept of horizontal and vertical product differentiation and access to sources of knowledge has been linked to product quality and innovative activity. Access to knowledge depends on the type of research and development (R&D) activity and network governance between firms.

Keywords: innovations, economic growth, competitiveness, technological fusion, triple helix, quality of products.

1. INTRODUCTION

There is no doubt that the main strategic goals of enterprises in the future are: surviving in good economic condition and satisfying the needs and requirements of customers better and faster than competition along the value chain [1]. To achieve such goals one must answer a variety of questions and find a way of solving numerous organizational and technical problems. Enterprises should consider changing dramatically market position, inventing new branches or redefining existing ones, discovering new rules of competition, new distribution channels, new value chain forms [2] and new production systems [3]. There exist various ways to respond to the problems mentioned, however, a critical determinant of organizational performance is introduction of new products or services [4,5] which in turn seek for new technologies and knowledge, can establish new markets and new market demands [6]. Many sources on new product or service introduction stress the enterprise's innovation ability as the result of creation, management and maintenance of knowledge [1,7].

The absorption of knowledge, in turn, results from R&D across industries and countries and good cooperation between researchers and practitioners [8]. The most remarkable absorption occurs in the US, Japan, Germany, France, the United Kingdom, Canada, Italy, the Netherlands and a few other countries. This absorption has been used by OECD for classification of industries into four categories, namely: high-technology, medium-high-technology, medium-low-technology, low-technology industries. in which relative importance of the following characteristics differs:

- intensity of R&D activity,
- level of innovation,
- diffusion of innovations,
- economic risk,
- adulteration of investments and product technologies,
- product life cycle,
- internalization, co-operation, networking between industries, research institutions in and between countries,
- competitiveness.

Innovative ability was not a subject of serious and deep studies in the theory of economy which follow early work by Joseph Schumpeter [9]. The studies by Paul Romer published in 1986 indicated that technical progress is the main driver for economic growth [10]. This growth could be measured via several indicators e.g. GDP, labour productivity, export of products etc. for a given economy. Technical progress improves transformation of resources and expenditures into products. The renaissance of interest of scholars into this subject has been revived recently after OECD published a report concerning Technology Economy Programme [11].

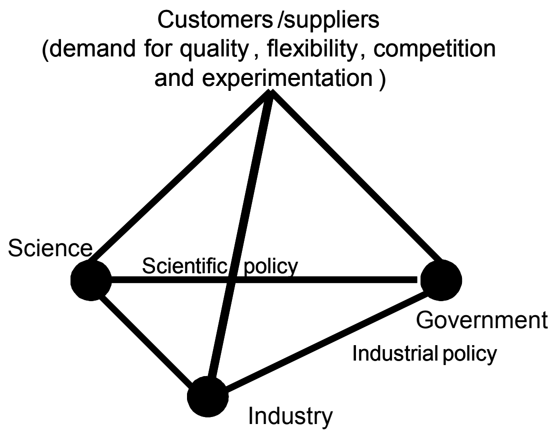
The aim of this paper is to analyze the current state and newest achievements and developments in theory of innovations. On this ground, the discussion of relationship between summary innovative index SII and macro economical indicators for several countries will be held. The place of Poland in these two dimensions will be shown among OECD and European Union countries.

2. INNOVATION AND INNOVATIVE ACTIVITY

The literature on innovation is very voluminous and diverse [8,9,12,13]. The core of innovation is inventing the use of production resources in a new, earlier unencountered way and simultaneous withdrawal of those resources from current application and use. Invention is an exhausting and tedious activity with a high rate of failure. According to Stevens and Burley [14] failure of inventions is very large on its way to commercialization. Approximately 3000 raw ideas are needed to produce 150 patent applications and one commercial success. Despite this, a continuous inventive activity is an element of success for traditional as well as high-tech firms [15]. During that time firm's resources are placed at financial risk. Several environmental factors influence the innovation process, namely degree of competition, availability of financial resources, manufacturing intensity and the size of the market [13], legislation, social norms, willingness of society to build the infrastructure [16] as firms do not exist in isolation.

One can find three actors on the innovative stage: industry/service, science and R&D, government (so called triple-helix) [17] to which customer could be added as a fourth actor [18]. The relationship between these actors can be visualized using the model of a pyramid (Figure 1). The nodes represent main actors, segments – relations between two actors, planes – relations between three, and volume inside – relations between all of them [18]. The position of government is strong and important as a source of scientific and industrial policy. The government is able to influence the customer, supplier and other actors. The power of science, or universities, is much weaker.

Figure 1. Model of pyramid (extended triple helix)



Classification of innovations is well established in the literature. One can distinguish four classification dimensions: subject carrier, significance, priority/originality and source of invention [19]. Relying on significance one distinguishes incremental and radical innovations [20,21,22]. Incremental innovations refine and improve an existing product, service, process or technology. By contrast, radical innovations are major transformations of existing products, services, processes or technologies that make the current product or design obsolete [23]. It is radical innovation which "disrupts an existing technological trajectory" [24] and "destroys the value of an existing knowledge base" [25]. Radical innovations are thus relatively rare. Products or processes generated by radical innovations are much better than previous products and processes, represent higher quality level, quality of type, technical or organizational maturity and in a better way respond to customer requirements. Radical innovation at its early stage is under the pressure of competitors who would like to imitate new products or processes. This leads to steady improvements. It has been pointed out that during the product life cycle incremental innovations are more numerous than radical ones, but they do exist in equilibrium with radical ones as so called "innovation oscillator" [26]. Incremental innovations are rather the effect of small steps on the way of continuous product quality improvement due to the single-loop learning, Deming's PDCA cycle [27], ISO 9001:2008 quality management standard and applied tools, e.g. SPC, Six Sigma, QFD along the quality loop. The mentioned methods and tools can improve the quality of product step-by-step along its life cycle. However, the technical or organizational potential of an exploited process or technology will reach its maximum after some time and will then decline. Perhaps, so-called, "lifting" will prolong the product life cycle a bit. Then, in turn, radical innovation based on new science and technology is requested to 'revive' the product and 're-charge' the process. Radical innovations are the effect of commercialization of scientific discovery, "blue-sky" research and intensive R&D activity.

Among the product innovation the special place is occupied by **network product innovation.** They refers to the process of integrating resources, information, marketing orientation and knowledge distributed within a group (network) of partnering firms (e.g. alliances, clusters) to achieve product innovation. This process is known as knowledge integration [28] which leads to products with better inherent characteristics and performance, thus better quality for final user. Takeuchi and [29] suggested, that most the efficient way to obtain multifunctional products is through team work. Knowledge integration supported by new technology of information treatment and communication shifted competitive advantage from large vertically integrated enterprises towards a vertically integrated network of small firms applying competitive advantage of localization [30] and mechanism of flexibility [21,26]. Firms in networks can effectively fuse their technologies [31] or integrate them [32].

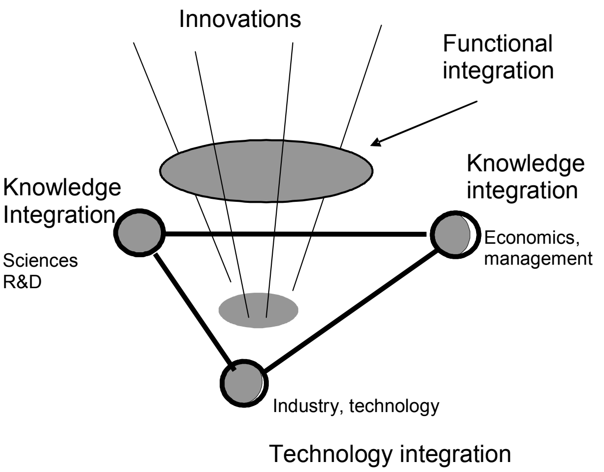
Technological integration is a nonlinear activity supported by cooperation, complementariyy and synergy between parties. It differs from linear substitution of old technology with a new one.
Then one can say, that research cooperation unifies enterprises from different sectors, and not different enterprises from the same one to gain synergy effects. Isanti and West [32] argued that now only few enterprises are able now to conduct R&D activity in all domains of interest in contrast to the 70s and80s. It is now, that process and technology integration become a critical competitive advantage and competence.

Knowledge integration is the next important condition for achieving product innovation from sources which are numerous, different and dispersed. According to Subramanian and Youndt [20] an enterprise gains competitive advantage from the integration of individual's knowledge. This statement could be extended on knowledge integration in network of firms. The main mechanism allowing this integration is social capital. Social ties (behaviors) enhance knowledge exchange and support innovative activity [33]. Small specialized networks of enterprises, which apply localization advantage, are able to compete with large firms linked horizontally. Finally, it is suggested to describe knowledge integration as linkage of complementary resources over (above) organizational barriers with an aim of new, market-oriented products. This goal is achieved through knowledge sharing and effective communication. Utilization of valuable information and use of appropriate communication channels depends mainly on workforce skills and abilities e.g. social capital of individuals and social capital of given a organization, collaboration and co-creation. Its effectiveness depends on trust among individuals and organizations.

Functional integration of R&D, production and marketing activities has been identified as a critical success factor in new product development processes leading to better commercial value [34]. Greater dispersion of market demands and increasing possibilities of fulfilling them through available production means an increase in the number of new products. It is an outcome of experimental research in enterprises introducing new products especially high-tech to the market. The basic argument in favour of integration is the increase of information content and capacity available for the new product development team. In turn: problem understanding knowledge of possible solutions and output capacity increases [34]. Provision of high quality information to the consolidated team should bring a positive outcome: shortening the development and time-to-market period. Conflict may in turn negatively impact a team's proficiency and execution of the development process. Michael Song and Mitzi Montoya-Weiss [34] argued that "technical development activities differentially contribute to project performance under conditions of high and low perceived technological uncertainty".
On the ground of discussion on technology integration, knowledge integration and functional integration it is possible to present the integrated innovation model (see figure 2).
The first step is integration around nodes. For example integration of chemistry, biochemistry, biology and other

natural sciences results of research, patents, applications etc. Integration in the management and economics node apply to production management, organization management marketing, market research, cost analysis etc. consolidated around developed product. And finally technology and technique node needs integration of engineering, material science, nanotechnology, process engineering and many others. Integration of knowledge, skills and resources in particular nodes does not produce extra value and is visualized as a spot on the triangle surface. However, understanding relationships and impacts between any two, or even better all three nodes, gives the extra value of a strong synergy effect. As a result, the spot from surface rises up and increases its surface in proportion to its value. This is represented by a cone image. The broader and stronger integration, the larger the cone base.

Figure 2. Model of integrated innovations



Source: own studies.

3. INTELLECTUAL CAPITAL AND INNOVATION

Modern, high-tech innovations emerge as a result of pooling and integration of multiple and diverse particles of knowledge. An organization collects individuals and accumulates their knowledge by various means for use at present or in the future [35]. In addition, an organization can create internal systems and processes for conversion of individual inputs into innovative outputs or can share appropriate resources via consortia or alliances with external partners.

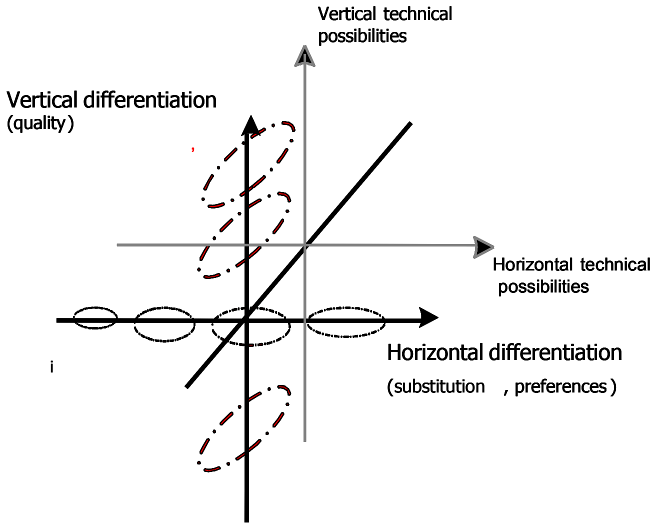
Intellectual capital was approximated by three main components: human, organizational and social ones [36]. "Human capital is described as the knowledge, skills and abilities residing and utilized by individuals" [20]. The organizational component is the institutional knowledge and experience residing within and utilized through databases, patents, manuals, instructions, systems, structures and processes. A.C. Inkpen and E. Tsang [37] define social capital as trust affecting intercompany knowledge transfer and creation based on competence, benevolence, assessment of cost and risk. Trust is a key factor in knowledge sharing of actors. The other are: access to information, opportunities for new business or ideas, understanding the norms etc. in intra- or internet work [32, 37].

Subramanian and Youndt [20] investigated the influence of intellectual capital on the incremental and radical innovative capabilities. The survey was carried out twice (repetition after three years). It was concluded that incremental innovation depends mostly on social capital and small influence of organizational or human capital. Radical innovation, however, relies on social capital with small influence of organizational and negative impact of human capital component.

4. TECHNOLOGICAL OPPORTUNITIES, PRODUCT DIFFERENTIATION AND QUALITY

Innovations, in turn, allow enterprises to differentiate, give rise to imperfect competition and growth of market share and finally strengthen again innovative ability in endless cycles. According to Tong [38] two broad categories of differentiation related to innovations exists: horizontal product differentiation and vertical differentiation (or advantage) shown in Figure 3.

Figure 3. Horizontal and vertical product differentiation



Source: own drawing inspired by Tong [38].

Horizontal product differentiation which increases possible substitution between products and decreases price competition between rival firms was addressed in the 80s by Michael Porter [30]. It emerges from heterogeneity of consumer preferences rather than state of applied science and technology. Extension of product lines or manufacturing me-too products does not need much science. The opposite is observed in high-tech industry (e.g. biotechnology, pharmaceuticals, space equipment, IT) where vertical technological opportunities are key success factors.

On the other hand, vertical differentiation relies on high product quality, low production cost without loss of accepted quality as compared to rivals. Offering products of high quality at reasonable prices increases competitive advantage and deters competitors. Sometimes, higher quality of an innovative product increases the cost of product. Customers are happy to pay more for better quality related to type and functionality, higher performance, lower cost of use (e.g. energy, fuel), durability, which increase customer satisfaction. This can lead to a spread of quality of type/cost relationship along the axis of vertical differentiation. Thus, vertical differentiation could be assumed as a source of strategic advantage [30]. Both horizontal and vertical differentiation work on the condition that appropriate technological opportunities will be at the disposal of firms.

Horizontal and vertical technological opportunities as a base for growth through research and development are intensively exploited in literature. For example, a "quality ladder" model [39] suggested successive replacements of older technologies with newer ones and resembles incremental innovation pattern or "patent race" models. Horizontal technological opportunities will be necessary to provide horizontal product differentiation as a response to customer preferences. From the technical and technological point of view such opportunities are easier available and easier to copy and do not require a lot of science. However, vertical technological opportunities relate to quality/cost differentiation of products offered by more ambitious industries. Those industries conduct own R&D activity and use patents to bring few firms to a dominating market position (e.g. Airbus, IBM, HP, Microsoft, Monsanto).

Vertical technological opportunities in the hands of large high-tech industries yield a tremendous escalation of R&D and significant market position. According to Tong [38] the existence of high-tech, high-capability firms comes from higher than average vertical technological opportunities, and innovation potential. Such firms, being leaders at a given time, rely on high R&D intensity, concentrated market and enhancing quality of products (escalation mechanism). However, if a management system is underdeveloped then investment in R&D will vanish and fail.

Competitive advantage is gained by these companies which are able to best use selected technologies, not those which create these technologies.

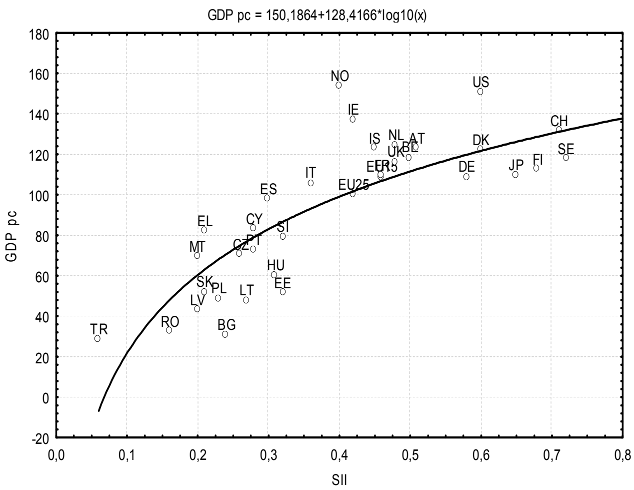
5. RELATIONSHIP OF INDICATORS: ECONOMICAL GROWTH AND INNOVATIVE ACTIVITY

Economical growth on a macro scale is approximated by several indicators e.g. GDP, GDP per capita, productivity or labour productivity, export of products etc. for a given economy. Innovative activity of nations is a complex, multidimensional construct.

Innovative activity of the European Union states is measured through SII (Summary Innovative Index) [40] which uses data from 26 indicators distributed over 5 innovation dimensions (innovation drivers, knowledge creation, innovation and entrepreneurship, applications and intellectual property). Sweden enjoys the highest SII value at 0.67, while Turkey has the lowest value at 0.08. Poland with SII = 0.22 belongs to catching-up or trailing countries, depending on the year of study.

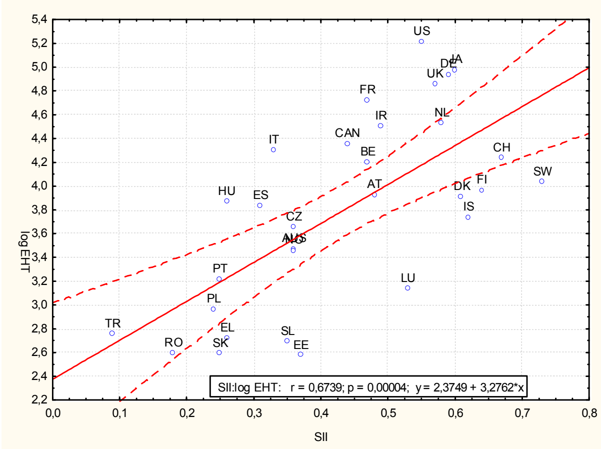
The relation between GDP per capita and SII for European and selected other countries is shown in figure 5 as a curve-linear semi-logarithmic plot. The similar plot for GSII is linear with Pearson correlation coefficient r = 0.786 [41].

Figure 5. Relationship of GDP per capita and SII for European and other countries



Figures 6-9 present relationship (linear or semi-logarithmic) between Summary Innovative Index SII and various indicators describing the economical growth, taken from World Competitiveness Yearbook 2007 [42]. Figure 6 depicts relationship of high-tech products export (in million USD). Countries above the plot export more than come from SII value. It means that USA, Japan or Italy, for example, are more efficient. In contrast, leader in SII ranking – Sweden exports less than comes from the equation. The same is true for Luxemburg, Estonia or Slovakia, for example.

Figure 6. Relationship: export of high-tech products EHT (as a logarithmic function) and SII in EU and OECD countries



The relationship between expenditures on R&D and SII with high correlation coefficient shows that Japan, USA, Iceland and Norway (top line as an example) pay relatively more on R&D than indicated by their SII ranking (see Figure 7). Countries lying bellow the regression line (Ireland, Netherlands, Estonia) posses higher SII rank than the relationship suggests. The meaning of this outcome is that USA and Japan spent a lot on financing basic research, which through diffusion is distributed to other countries.

Labor productivity is only weakly related to SII (see figure 8), and correlation coefficient r=0.58. Some countries above the line (e.g. Luxemburg) indicate higher productivity than their SII ranking allow. Labor productivity in some other countries is lower (e.g. Sweden, Switzerland) than calculated from the equation. This means a deficit in productivity, and that productivity depends on some measures not included in SII.

Figure 7. Relationship: SII and R&D expenditures in EU and OECD countries

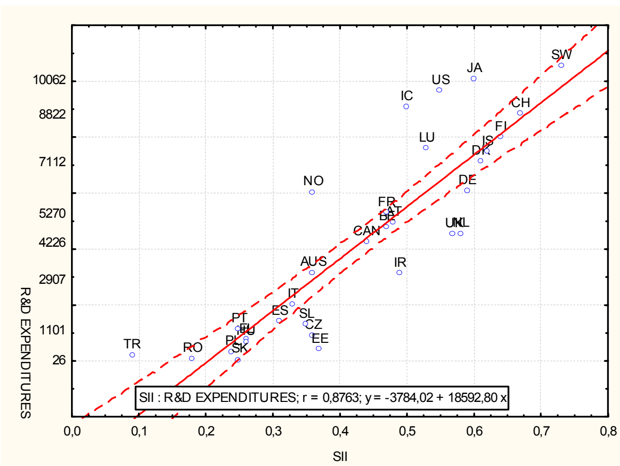


Figure 8. Relationship: labour productivity (in USD per worker) in industry and SII in EU and OECD countries

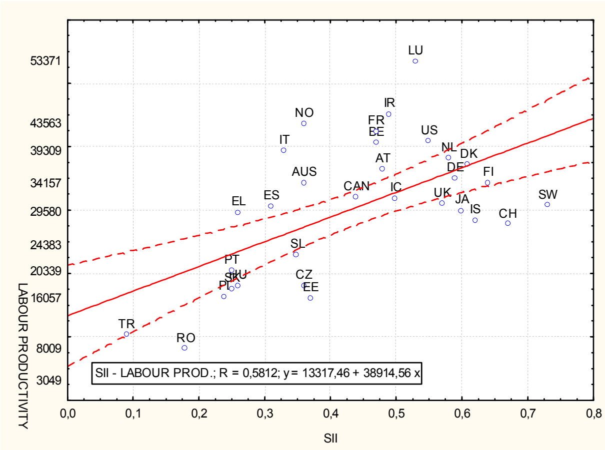
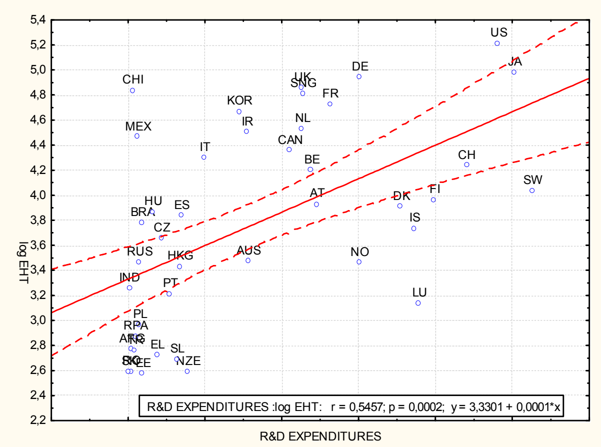


Figure 9. Relationship: export of high-tech products and R&D expenditures in selected countries



Many countries are very effective in exporting high-tech innovative products. In this group we can find high diversity in magnitude of research and development spending. For example high rated China and Mexico, as figure 9 indicates. The explanation of China's case is imitation of high-tech products from developed countries, foreign direct investments and location of very modern facilities and technologies there due to low cost of labour. A vast number of countries are poor in high tech products export despite high spending on R&D. Sweden, Switzerland, Luxemburg are most visible examples.

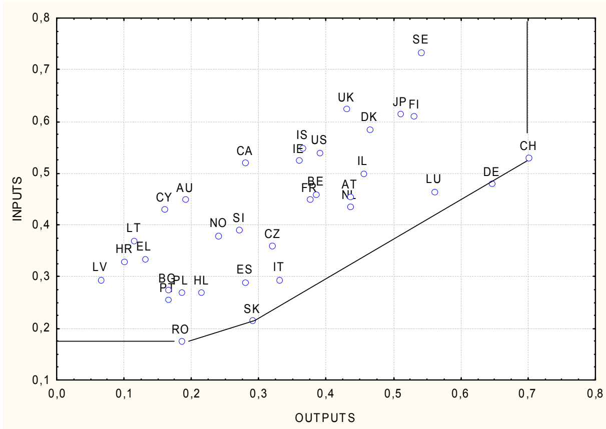
Unfortunately data and 26 indicators for non-European countries are not available. The Global Summary Innovation Index [41] uses only 9 indicators identical with SII and add three proxy indicators. There is a good rectilinear dependency between the SII and GSII indices for a number of countries, for which data are available.

It is well know that European Union innovative activity is unsatisfactory. The innovative gap towards USA and Japan is large but closes down slowly. It is due to Lisbon strategy imposed in 2000 [43] which insists on increasing funds on R&D to the level of 3% of GDP. Unfortunately the spread among countries is from 0.5% to much more than 3.5% GDP with the average for all EU close to 2%. Also, innovative activity in USA, Japan, Israel, and some other countries is decreasing in relation to the rest of the world. This brought into light the important problem of efficiency of spending on R&D in the innovative process (see the case of China above). H. Hollanders and F.C. Esser [44] developed an efficiency measure relying on a country's position on the graph input coefficient–output coefficient, against efficiency barrier. This barrier spans between points (countries) for which product:

output coefficient / input coefficient

is largest. The idea of this methodology is presented in figure 10.

Figure 10. Efficiency barrier of innovative activity in OECD countries in 2006



Source: Hollanders, Esser [44].

However, the efficiency of using available resources decreases towards the top left corner of the graph. For example Switzerland and Germany has a high efficiency of resource utilization than Sweden, and Romania or Slovakia than Hungary or Croatia. Figure 10 provides arguments to support the claim that the group of countries using a significant share of their GDP on R&D (e.g. USA, Finland, Japan, United Kingdom) achieve poor results compared to outlays. However, it is also a problem that Romania and Slovakia achieve high effectiveness of involved funds, but at a low absolute level and stay in the group of countries with poor SII score.

6. CONCLUSION

Economical growth on a macro scale is approximated by several indicators e.g. GDP, GDP per capita, productivity or labour productivity, export of products etc. for a given economy. It is agreement in the literature that the engine of growth is innovation and quality. Thus the latest outlines of innovative activity have been summarized. Innovative activity of nations is a complex, multidimensional construct exemplified by Summary Innovative Index SII for EU countries and Global Summary Innovative Index GSII.

The relation between GDP per capita and SII for European and selected other countries is found to be a curve-linear semi-logarithmic plot. The similar plot for GSII is linear with Pearson correlation coefficient r = 0.786.
Relationships between:

- export of high-tech products EHT (as a logarithmic function) and SII in EU and OECD countries,
- SII and R&D expenditures in EU and OECD countries,
- labour productivity (in USD per worker) in industry and SII in EU and OECD countries, and finally,
- export of high-tech products and R&D expenditures in selected countries,

in 2006 have been drawn and parameters of mathematical equations were calculated. The explanation of observed phenomena in terms of nation's innovative ability has been undertaken. The main conclusion is that efficiency of R&D spending in the innovative activity of nations should be the main goal of analysis in future. For example why some innovative countries spending high percentage of GDP on R&D achieve medium results in terms of export of high-tech products or labour productivity.

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