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INNOVATION SYSTEM: A STRUCTURAL STUDY FOR POLAND*

SYSTEM INNOWACJI: UJĘCIE STRUKTURALNE DLA POLSKI

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Summary: Most countries implement a policy supporting the commercialization of research. There are several institutionalized forms and initiatives supporting research, development and innovation (RDI) transfer between university and business. The research is driven by the question of Polish RDI institutions' efficiency and effectiveness, while more generally it aims to contribute to a theoretical understanding of the innovation system. The article builds on the economic studies of the National Innovation System (NIS) and Triple Helix Concept, highlighting the need for a structural style study. This is used to create a NIS case study for Poland, and provides an audit of systemic features and issues based on qualitative information, using a particular framework respecting three levels of stakeholders and investment viewpoints. The research has a descriptive but also a normative character.

Keywords: NIS, Triple Helix, research and development infrastructure, evaluation.

Streszczenie: Większość krajów wdraża politykę wspierającą komercjalizację badań. Istnieje wiele zinstytucjonalizowanych form i inicjatyw wspierających transfer badań, rozwoju i innowacji (RDI) między uniwersytetem a biznesem. Niniejsze opracowanie stawia pytanie

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o efektywność polskich instytucji badawczo-rozwojowych, bardziej ogólnie zaś – może przyczynić się do lepszego zrozumienia systemu innowacji. Artykuł wykorzystuje koncepcję Narodowego Systemu Innowacji (NSI) i koncepcję potrójnej helisy, podkreślając potrzebę badania struktury organizacyjnej systemu innowacji. Opracowanie przedstawia studium przypadku NSI dla Polski i umożliwia przeprowadzenie swoistego audytu struktur organizacyjnych wspierających transfer badań, rozwoju i innowacji. Badanie oparte jest na informacjach jakościowych według schematu uwzględniającego trzy poziomy interesariuszy i trzy perspektywy inwestycyjne. Badania mają charakter opisowy, ale także normatywny.

Słowa kluczowe: NSI, model potrójnej spirali, infrastruktura badawczo-rozwojowa, ewaluacja.

1. Introduction

The economy's development based on knowledge and innovation has been a necessity for many countries of Central-East Europe, including Poland [European Innovation… 2006; European Commission 2014]. A knowledge-based Economy has evolved from the National Innovation System (NIS) from an evolutionary perspective [David, Foray, 2002]. NSI is a model for conceptualizing the innovation [Ranga, Etzkowitz 2013]. According to Klincewicz [2008], the NIS concept helps in the assessment of innovativeness of the national economy which is a challenge for researchers. There is no common or agreed approach to innovation system definition and its empirical verification even though the European Union [European Innovation… 2006], Organisation for the Economic Development [OECD 2005], United Nations [WIPO 2007] carry out research in the area.

This study falls into the stream of research relating innovation system in a structural (organisational) context. This fits into the discussion about innovation system definition, its components, efficiency, and effectiveness. It builds on the economic studies of NIS and Triple Helix, highlighting the need for a structural study. Using a specific framework, concepts of NIS and Triple Helix are used to create a system innovation case study and provide an audit of systemic features and issues. The research provides then an explanation of the efficiency and effectiveness of Polish NIS and contributes to a better understanding of the innovation system in general. The following part of the paper presents a literature review. The structural study of NIS in Poland applying a specific framework analysis is in Section 3. The conclusions close the study. The research is based on literature, documentation and reports of the Polish Agency for Enterprise Development (PARP) applying methods of critical analysis and construction.

2. Literature review

NIS is a network of cooperating institutions in the public and private sectors [Freeman 2004]. Their activities and interactions initiate the importation, modification and diffusion of new technologies. Nelson [1993] defined NIS as a set of institutions whose interactions affect domestic companies' performance [Nelson (ed.) 1993]. Metcalfe

[1995] added that NIS embraces institutions which collectively and individually influence the development and diffusion of new technologies. These institutions are individual or collaborating private firms, educational bodies, societies, associations, and government laboratories and they create a structure within which governments implement the innovation policy. Local studies define NIS as a complex of interrelated institutional and structural factors in the economy and society which generate, select and absorb technical innovations [Okoń-Horodyńska 1998]. Thus the NIS embraces numerous organisations, institutions and relations between them. The structural dimension of NIS is consistent with the narrow definition of NIS which includes "organisations and institutions involved in searching and exploring" [Lundvall (ed.) 1992, p. 12]. These organisations and institutions, as well as the relations among them and their functions, are elements of the Triple Helix concept, therefore Triple Helix can be considered as multi-centered [Leydesdorff, Ivanova 2016] institutional elaboration [Etzkowitz, Leydesdorff 2000]. It is an "analytical construct that synthesizes the key features of university-industry-government (Triple Helix) interactions into an innovation system format" [Ranga, Etzkowitz 2013, p. 237]. Components are institutional spheres of university, industry and government although "innovation is not taking place within administratively bordered nations" [Leydesdorff 2018, p. 1]. Relationships include collaboration and conflict moderation, collaborative leadership, substitution, technology transfer, networking. Functions, which represent components' competencies, determine the system's performance. Ranga and Etzkowitz state [2013] that the potential for innovation and economic development depends on the leading role of the university and the connection of university, industry and government. The components of the (Triple Helix) concept and the organisational dimension of NIS justify the theoretical perspective of this research focusing on the structural perspective. The generic name for the institutions is research, development and innovation (RDI) infrastructure [European Commission 2014]. The research assumes that the RDI infrastructure stimulates innovation transfer and have a key role in promoting industrial innovation and economic growth [Fagerberg 1987; Nadiri 1993; Eurostat 2014].

Assessments of RDI infrastructure have been then carried out across the world at different levels of detail, depth, and conclusions. For instance, Colombo and Delmaestro [2002] confirm the effectiveness of technology incubators in Italy. The preliminary results of Siegel, Westhead and Wright [2003] suggest that firms located on university science parks in the United Kingdom have only slightly higher research productivity than observationally equivalent firms not located on university science parks. Johnson and Jacobsson [2003] claim that the performance of an innovation system can be assessed based on the "functionality". Ratinho and Henriques [2010] call for an approach reflecting the diverse stakeholders' requirements and societal and organisational context. Sveiby, Gripenberg and Segercrantz [2012] call for an efficiency and effectiveness approach, and the incorporation of intentional but also unintentional consequences. The European Commission [2014] postulates to use also relevance criteria in assessment in order to verify whether project (RDI infrastructure) effects are relevant to identified needs. Wojewnik-Filipkowska and Kowalski [2015] performed a cost-benefit analysis confirming the effectiveness of selected industrial-technology parks in terms of socio-economic development.

According to Pisu, Hoeller and Joumard [2012], there are basic approaches which can be applied to assess RDI infrastructure. This is macro-econometric modelling, among others, which is generally based on the estimation of the relationship between infrastructure capital expenditures (stock) and economic growth. The other approach takes external effects into consideration providing a welfare perspective. This research is built on the second approach. The incorporation of the external effects in the assessment is particularly important in the case of the public sector being responsible for developing NIS whose objectives are national, although the RDI organisations are developed at local and regional levels. As institutionalised forms supporting research, development and innovation are various entities [Gower et al. 1996; Colombo, Delmaestro 2002; Hansson et al. 2005; Ratinho, Henriques 2010; Cumming, Johan 2013; Awang et al. 2013], they have different mission and objectives. They also require different input and deliver different effects. This research analyses RDI infrastructure in terms of the criteria of efficiency and effectiveness according to stakeholders on three levels. It creates a specific system innovation case study and provides an audit of the systemic features and issues relating to the Polish NIS.

3. A structural study for Poland

A specific framework analysis was designed and applied to provide an explanation of the Polish NIS. It provides an audit of systemic features and issues of RDI infrastructure. It considers commercial and welfare perspective (different investment viewpoints) including the efficiency and effectiveness criteria of different types of RDI infrastructure, their direct and indirect effects on three stakeholder levels (Figure 1).

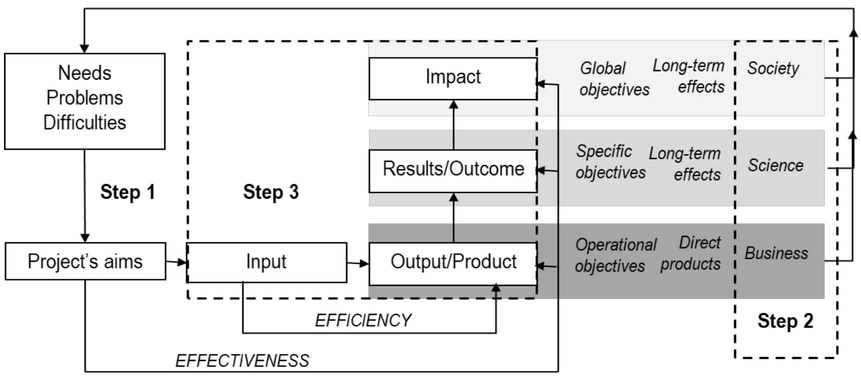


Fig. 1. Framework analysis of RDI infrastructure

Source: own study.

The framework analysis includes the following steps:

1. Identifying the type of RDI infrastructure (project).
2. Identifying stakeholders.
3. Identifying input and three level effects.

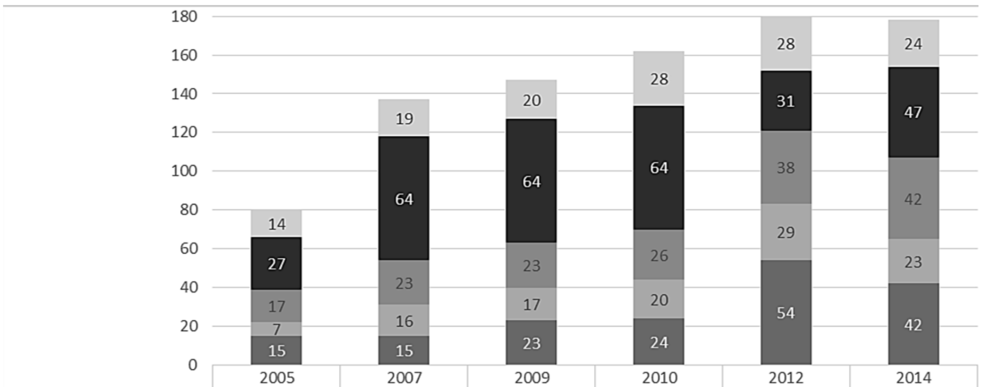
Step 1 The RDI infrastructure in Poland includes science parks, centres of technology transfer, innovation centres, technology incubators, and academic incubators (Table 1). Factors which contribute to the development of innovation, including legal regulations, as well as the trends and effects of institutional support of innovation in Poland, show that the RDI infrastructure system is still at an early stage of development [Bąkowski, Mażewska (eds.) 2014; 2015].

Table 1. General characteristics and specific aim of different types of RDI infrastructure

RDI infrastructure	General characteristic	Specific aims
Science parks	Usually organised in the form of a special zone; a group of separate buildings, including technical infrastructure created to make the flow of knowledge & technology between scientific & business communities using modern technologies.	Innovation implementation, the flow of knowledge, attracting new investors, employment increase.
Technology transfer offices	Units developed by firms affiliated with the universities or scientific institutes in order to sell or transfer the results of research & development; constitute entrepreneurial university concept.	Preparation of research commercialization & technology transfer offers; provide services, advising training & promotion for academic staff.
Innovation centres	Support new products & technologies commercialisation; focus on providing innovation, technology & service expertise, primarily to companies &, to a lesser extent, public organisations & universities; support & promote business-type high-tech companies whose operation is connected with a high degree of risk.	Innovation implementation, the flow of knowledge, attracting new investors, employment increase.
Technology incubators	Usually provides shared facilities, business support & advice, sometimes access to financing; leverage entrepreneurial talent by linking it with other talents, know-how, and financial resources to commercialise business ideas.	Assists technology-based companies during their start-up and beginning phases, employment increase.
Academic incubators	Support business activities of the academic staff of universities & students; constitute an entrepreneurial university concept.	Company creation, employment increase.

Source: own study.

The total number of RDI entities doubled in the research period – from 80 entities in 2005 to 178 entities in 2014, according to the latest available data. The highest increase in the number of entities occurred between 2005 and 2007 when 57 new entities were developed. The structure does not vary so much, as innovation centres represented the highest share of entities in every year except 2012. Between 2005 and 2010, almost 50% of the entities were launched due to European Union accession in 2004. This was achieved with a large proportion of subsidies of the structural funds which remains an important source of funding innovation activities (Figures 2 and 3).



	2005	2007	2009	2010	2012	2014
Academic incubators	14	19	20	28	28	24
Innovation centres	27	64	64	64	31	47
Technology transfer office	17	23	23	26	38	42
Technology incubators	7	16	17	20	29	23
Science parks	15	15	23	24	54	42

Fig. 2. Development of the number of RDI infrastructure in Poland (2005-2014)

Source: own study based on [Bąkowski, Mażewska (eds.) 2014; 2015].

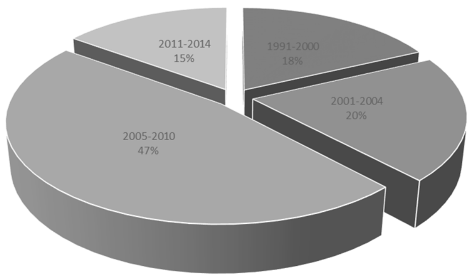


Fig. 3. The age structure of RDI infrastructure in Poland at the end of 2014

Source: own study based on [Bąkowski, Mażewska (eds.) 2014; 2015].

Step 2 According to PARP [Bąkowski, Mażewska (eds.) 2014;], approximately 63% of the stakeholders cooperating with technology transfer offices are researchers. The largest group of stakeholders at innovation centres are budding company owners (54%) and entrepreneurs (20%). The main customers of academic incubators are students (44%). There is a lack of information about stakeholders relating to science parks and technology incubators (Figure 4).

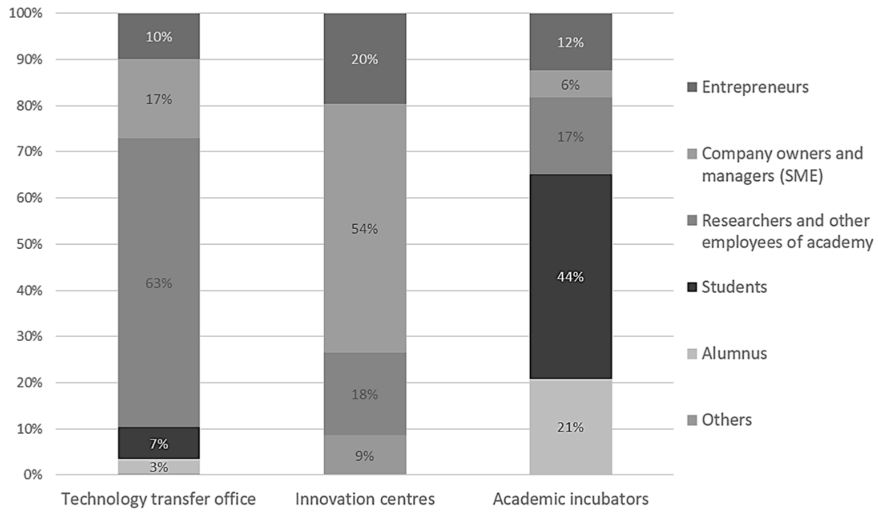


Fig. 4. Cooperation of RDI infrastructure with different stakeholders in Poland in 2014

Source: own study based on [Bąkowski, Mażewska (eds.) 2014; 2015].

Step 3 Typical investment costs (input, resources) and also operational products are related to the specific RDI (Table 2). Different forms of RDI infrastructure have different missions, objectives, functions, forms of action and organisation, and therefore require different input.

Table 2. Typical input (resources) and operational products of RDI infrastructure

Input (resources)	Operational products
• Planning and design costs • Land acquisition • Construction costs • Human resource, materials • Utilities (energy, waste, etc.) • Road access • Equipment, IT • Intellectual property purchase • Testing • Start-up costs	• License revenues from patent commercialisation • Sale of consultancy services • Revenues from industrial research contracts and pre-commercial procurement contracts • Revenues from the target population for the outputs • Entry fees to the laboratory and for the use of research equipment • Research grants • Revenues from outreach activities to the wider public (e.g. bookshops) • Revenues from sale or rental of buildings • Student/master's/PhD fees • Spin-off equity realisations • Spin-out equity realisations

Source: own study.

The required input determines the financial efficiency which is the subject of project evaluation at business level. The most complex RDI infrastructure are science parks, innovation centres and technology incubators as they require the most diverse investment expenses. Centres of technology transfer and academic incubators benefit in that case from close relations with universities and they are able to exploit the existing infrastructure, at least to some extent. However, this fact may impede their activities. The second component of financial efficiency is output considered as revenues from a financial efficiency perspective. All the revenues refer to products generated at the first level of the analysis which are benefits for the business directly. These are operational products. For instance, all RDI infrastructure in Poland generate revenues from consultancy service and research grants involving the

Table 3. Components of RDI infrastructure assessment from the stakeholders' perspective

Effects / **Stakeholders**		**Aims/benefits**		
		Direct measurable effects	Long-term effects for direct & indirect stakeholders	Long-term effects for indirect stakeholders
		Output/products	Results/outcomes	Impact
Business	New business	No. of established start-ups, spin-offs, spin-outs	Decreased business mortality, avoided cost due to the services provided by the R&D facilities, development of new or improved products and processes.	
	Existing business	Number of jobs created	Development of new products and processes, in some cases leading to patents or other forms of protection of intellectual property.	Knowledge spill-overs, support for the development of new or improved products and processes, equipment, materials and software, benefitting from learning-by-doing effects.
		Income-related development	Increase the attractiveness of a cluster or science park for investors and companies.	
		Costs avoided		
Science	Students	No. of graduates of specific fields to foster smart specialisation	Stimulate students to take up scientific studies & undertake a career in a specific scientific area.	
	Researchers outside academia	No. of established start-ups and spin-offs	Development of human & social capital through networking. Reduce 'brain drain' by promoting the development of I&TT infrastructures. Mobility & exchange of ideas promotion. Strengthen the cooperation between research, innovation, education & business to increase economic competitiveness. Development & strengthening of national research systems, ensuring optimal transnational cooperation & competition among researchers, guaranteeing knowledge access & transfer.	
	Academic and researchers	No. of publications, citations, patents, etc.		
Society	Group related to environmental risk		Acceleration of the development & deployment of innovative, enhanced, more efficient & higher value-added products, processes or services.	Costs avoided & lives saved in relation to environmental risks.
	Group related to health risk			Avoided mortality & increased quality of life.
	Group related to cultural effects			Related use-benefit is in terms of cultural effects.
	Society as a whole			Technological spill-overs potentially generated from large-scale projects.

Source: own study.

transfer of ownership of specific research output. At the same time, none of them generate revenues from outreach activities to the wider public or take fees from students. Development of spin-offs and spin-outs can simultaneously refer to the second level of effects as they are the result/outcome for science. Therefore, spin-offs and spin-outs can be regarded as both direct products affecting stakeholders, in fact – shareholders, on the first level (business and project perspective), and as specific effects affecting stakeholders on the second level (science). The first level is connected with efficiency analysis while the second level requires effectiveness analysis, which will also be applied for assessment at the widest perspective where a relationship between resources and all results, including the impact on the third level, is assessed.

To sum up, in order to organise the RDI infrastructure assessment, the three-level effects (output, results/outcome, and impact) can be related to the three main groups of stakeholders driving demand for the project [European Commission 2014]: a business which benefits from the services provided by the project at the first level of direct effects (products) of the project, a science community which uses the facility to do their research to increase scientific and technological knowledge relating to longer-time effects (impact) at the second level, and finally, society as a whole which is influenced by the project impact indirectly, including spill-over effects, at the third level. The assessment on the first level is based on efficiency. The assessment on the second and third level requires the application of effectiveness analysis methods using more sophisticated methods such as cost-benefit analysis (CBA). Table 3 illustrates the three levels relating to stakeholders and the effects.

4. Conclusion

Despite the constantly growing expenditure on innovation in Poland, there is still a lack of innovation transfer channels from universities to business and a lack of a comprehensive long-term perspective in innovation policy. The development of RDI infrastructure in Poland has been observed for about a decade – which is a relatively short time to observe the impact (long-term effects). It was reformed in 2010-2011, but so far it has not generated significant changes in the output, either. The three-level approach to RDI infrastructure efficiency and effectiveness assessment enables to identify barriers of RDI infrastructure efficiency and effectiveness and classify them into three groups to improve the situation. These groups are connected with the corresponding specific categories of stakeholders and levels of effects: business, science and society (Table 4). The first group of barriers are obstacles identified at the level of companies. The second group relates to the science community. The last group are systemic barriers which occur throughout the country and affect all entities involved in the innovation transfer.

Table 4. Barriers of RDI infrastructure efficiency and effectiveness at three levels

Level	Barriers
Business	• incomprehension at the specifics of the university, • excessive expectations regarding the quality and level of advancement of technologies developed at the university, • SME sector has little capital, which may be intended for innovation, • lack of understanding of the concept of "win-win solution"; more funds transferred to universities accelerate the development of subsequent technologies, • a different perception of time by science and business.
Science	• universities have technologies at a low technology readiness level (TRL), • high expenses associated with the development of technology, starting with the description of the project to the prototype, • motivational barriers of researchers, • scientists' comfort zone, which means carrying out of research "for personal use", • "grey market" and the sale of ideas concerning new technologies for little money, • unclear procedures and criteria for the technologies valuation offered by universities, • lack of confidence among entrepreneurs and their principles used in the potential profitability of the technology evaluation process, • high costs of patent protection in the international procedures, • the reluctance of scientists to develop technology in the spin-offs or spin-outs, • bureaucracy, • lack of domestic model solutions for the commercialisation of technologies, • dispersed databases on completed or ongoing projects and their effects, • development of ambitious technologies which are not applicable in the business, • insufficient recognition of achievements resulting in doubling the research.
Society	• lack of a coherent strategy for the development of NIS including assessment policy, • lack of professional institutions supporting commercialisation of RDI, • the incoherent legal system, • no system of information exchange between science and business, • poor understanding of the processes of RDI commercialisation by civil servants who create frameworks for financial support for RDI infrastructure.

Source: own study.

The study allows us formulate certain recommendations. It is necessary to develop an ex-ante and ex-post evaluation system of RDI infrastructure based on three levels of stakeholders and investment viewpoints to improve its efficiency and effectiveness. The ex-ante approach should not be seen as an administrative step but as an investment justification based on the analysis of all benefits and costs. The three-level socio-economic analysis should take into account the characteristics of industry and technology aspects such as the dissemination of knowledge and business skills in companies, benefiting from new infrastructure, the establishment or relocation of new businesses and associated jobs, reputational effects, the overall reduction of costs associated with start-up, and saving on transportation costs.

Locally, the success of RDI infrastructure supports the image of the region and attracts tenants and talented people which is advantageous for building local support and networks. On the other hand, the negative spill-over effects should be considered. These effects have not been considered in the study which is one of the research limitations. The other important research limitation is that the study considers only the structural dimension of the innovation system and is not supported by comparative studies. The future research will continue on the innovation system in a global context, RDI infrastructure monitoring and updating the data as the information is not easily accessible. The Polish Agency for Enterprise Development runs analyses of the sector but they are not regular and not complete which limits comprehensive multidimensional analysis. The limitation of the research relates also to the fact that it is based on data only from secondary sources. Obtaining the primary data would be then the next step for further research.

In reference to the general purpose, the study contributed to the theoretical understanding of the innovation system and its components, thus having a descriptive dimension. At the same time, the results of the study may be useful for practice and inspire public policy, thus leading to a normative dimension. The original study results comparing the efficiency and effectiveness of different types of RDI infrastructure in Poland may not be generalized to the rest of the world in a straightforward way. However, the structural framework analysis can be a universal approach to provide an audit of systemic features and issues of RDI infrastructure in other countries to support RDI infrastructure development, its efficiency and effectiveness, identification of barriers, risks and opportunities of cooperation between science and business. It can help to formulate recommendations relating to national policies and regional development strategies on creating, supporting and financing RDI infrastructure as it is an important component of the system influencing local and national economic growth.

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