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Contact to corresponding author: Arkadiusz Świadek, a.swiadek@wez.uz.zgora.pl

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Arkadiusz Świadek
University of Zielona Góra, Poland
orcid.org/0000-0002-5566-3114

Piotr Dzikowski
University of Zielona Góra, Poland
orcid.org/0000-0002-5067-8552

Jadwiga Gorączkowska
University of Zielona Góra, Poland
orcid.org/0000-0001-6394-463X

Marek Tomaszewski
University of Zielona Góra, Poland
orcid.org/0000-0003-2590-5159

The National Innovation System in a catching-up country: empirical evidence based on micro data of a triple helix in Poland

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Abstract

Research background: There are two main directions for the research of the national innovation system (NIS): the international comparison of macro data from national statistic offices or specific micro research restricted mostly to analysing selected issues. There is a lack of empirical studies regarding the national innovation system as a whole based on micro raw data and using statistical models.

Purpose of the article: To identify and evaluate the impact of the triple helix (an input and output approach) on the NIS in Poland, including internal interactions between industry, science and government.
Methods: A questionnaire surveys were conducted by the authors over the past five years in 6,284 manufacturing enterprises. The multifactor stepwise logistics regression forward was used to evaluate what, where and how effectively the NIS institutions in catching-up and medium-sized countries such as Poland are working.
Findings & value added: The NIS of Poland is a complicated and non-mature system. Some parts of the network are effective, while others are not. It is noted that cooperation between enterprises stimulates innovation to a greater extent than cooperation with scientific institutions and public administration. The vertical supply chain is the main driver of NIS in Poland. Domestic scientific institutions have an impact that is often short-term, fragmented, and non-continuous, though it can be strong from time to time. Strangely, organizations with low knowledge potential support industry innovation activity more efficiently and in a more organised way than science institutes, excluding foreign ones. For catching-up countries, this is an important bridging of the knowledge gap - it turns out that the quantity and quality of domestic knowledge in the national innovation system is inefficient. Scientific institutions need to achieve sufficient critical mass to stimulate innovative activity. The value of the conclusions is underlined by the fact that the analyses were based on micro data, which allowed to capture the relationships between the different elements of the triple helix.

Introduction

National Innovation Systems (NIS) have been the subject of much research over the past thirty years. Currently, research on their phenomenon covers two directions. The first one has a macroeconomic dimension. It is based on national or international statistics from OECD, EU, World Bank or other institutions collecting statistical data. It enables research of innovation systems as a result of comparative studies of many countries — both developed and catching-up ones (Jankowska *et al.*, 2017, pp. 77–94; Nasierowski, 2019, pp. 79–104; Ilchuk & Mushenyk, 2018, pp. 78–85; Hudec & Prochadzkova, 2015, pp. 55–72). These analyzes are broad and necessary, but at the same time superficial. On the one hand, they make it possible to capture general development trends on a global scale, on the other hand the high level of data aggregation makes it impossible to identify relationships between parts of the system.

The second approach is to evaluate National Innovation Systems using micro data. This trend indicates the inclusion of the Triple Helix model, which illustrates the functioning of innovation systems on the basis of interactions between enterprises, public administration and scientific institutes. Scientists partially understand the individual elements of the Triple Helix and the relationships between them. Surveys contribute to the knowledge base, but compared to national and international statistical surveys based on microdata, they are rarely representative and usually allow hypotheses and predictions to be made with a very narrow scope. They contain analyses of the conditions of cooperation between enterprises (Coussi *et al.*, 2018, pp. 1751–1775; Nakwa *et al.*, 2012, pp. 52–61), between enterprises and public administration (Danson & Todeva, 2016, pp. 13–26; Saad & Zawdie 2005, pp. 89–103; Olkiewicz *et al.*, 2019, pp. 1–22) or scientific institutes (Villasana, 2011, pp. 43–53).

What is missing in this context is a holistic understanding of the National Innovation System in which all the elements of the Triple Helix are present at the same time and the research itself is concerned with the components of the network and the relationships between them. There are some studies on NIS from Spain (Hernández-Trasobares & Murillo-Luna, 2020) and South Korea (Lee *et al.*, 2020) that consider the relationship between Triple Helix elements. However, their number is limited and research methods in this field are in their infancy. Moreover, there is currently no research in this area in developing or catching-up countries.

The concept of National Innovation Systems (Lundvall, 1992, pp. 45–67) and the Triple Helix model (Leydesdorff & Etzkowitz, 2001, pp. 1–31) were developed on the basis of the economies of developed countries. The success they have achieved means that the solutions adopted in these concepts are readily replicated in catching-up countries. This is the right thing to do, because basing the building of support for innovation on interactions in the triple helix model makes it possible to improve innovation capacity in both developed and catching-up countries (Fitriani *et al.*, 2019, pp. 233–248; Kobzeva *et al.*, 2017, pp. 33–56). However, when building the support model, one should take into account the specificity and level of technological maturity of the countries where the solutions are implemented (Puangpronpitaga, 2019, pp. 565–572; Lee & Kim, 2016, pp. 93–105).

In this context, the analysis of the National Innovation System in a catching-up country can be reduced to the following problems:

1. Does each element of the Triple Helix (enterprises, government, science) act effectively, i.e. positively influence innovation activity?
2. Which actors have more influence on accelerating of technological progress in the system and why?
3. Do subsequent actors in the innovation system affect it in a sustained and multidirectional way, or incidentally and in an isolated way?

The authors of the study will attempt to answer these questions in this paper. The overarching aim of the study is to identify and determine the strength of influence and interrelationships of the successive elements of the Triple Helix in the National Innovation System in terms of inputs (entry into the system) and outputs (exit from the system).

The analyses are based on micro data collected by the authors of the paper. The use of micro data to study the National Innovation System provides an opportunity for a broader and deeper look at the relationships among the actors in the system. Moreover, collecting key relationships in a single model allows us to consider broad determinants. On the other hand, data available from public statistical surveys are aggregated, which makes it impossible to identify relationships between parts of the system. This has resulted in a single study that combines the advantages of analyses based on macro and micro data. This approach adds to the body of knowledge related to the use of the Triple Helix model in analyses of national innovation systems.

The analysis is organised as follows. Firstly, the paper will outline the functioning of the NIS in the context of the Triple Helix on the basis of global experience. Secondly, the research methodology adopted in the study will be discussed. Thirdly, the results of the study from the perspective of each model will be discussed. This will be followed by an assessment of the transformation of inputs into innovation effects from the perspective of the Triple Helix actors. Finally, conclusions will be formulated.

Literature review

Innovation systems have been the subject of much research over the past thirty years and were initiated by Lundvall (1992, pp. 45–67; 2007, pp. 95–119), Nelson (1993) and Freeman (1995, p. 5–24). At present, they are not considered a theory in the strict sense, but rather a framework of behavior aimed at accelerating the technological activity of enterprises. In this context, the National Innovation System can be distinguished. Analytically, it covers enterprises as participants in innovative processes and the institutional base determining their innovation activity (Filippetti & Archibugi, 2011, pp. 179–192). The relationships between them significantly affect the innovation potential and innovativeness of the economy (Watkins *et al.*, 2015, pp. 1407–1418; Lundvall, 2007, pp. 95–119). Recognition of the importance of interactions between NSI actors made them gain more and more attention. In this context, the concept of a triple helix was born.

The Triple Helix concept is based on the importance of creating innovations in a cooperative system between the three elements of the national innovation system: public administration, enterprises and scientific institutes (Leydesdorff & Etzkowitz, 2001, pp. 1–31). This model plays an important role in the process of creating innovation in knowledge-based economies by establishing a framework for the functioning of innovation systems (Leydesdorf, 2012, pp. 25–35). This is due to the fact that the absorption, creation and use of knowledge is related to the systemic Triple Helix maturity (Peixoto *et al.*, 2021, 92–110). High-income category countries are more effective in taking advantage of the opportunities offered by the Triple Helix (Mêgnigbêto, 2018a). They show better cooperation between universities and industry in the field of R&D and innovation activity in general (Aldabbas *et al.,* 2020, pp. 365–383; Mêgnigbêto, 2018b, pp. 1118–1132). This was confirmed by studies conducted by Medeiros *et al.* (2020, pp. 681–704), which indicated that the interactions between the elements of the helix in terms of innovation activity are better in the countries of Northern Europe (Finland, the Netherlands, Norway and Sweden) than in the South (Spain, Greece, Italy and Portugal). Thus, in developed economies, Triple Helix analyses are extended to include further elements that may affect the functioning of the national innovation system, e.g. international connections (Arranz *et al.,* 2020, pp. 1–15; Leydesdorf, 2012, pp. 25–35).

However, the situation is different in catching-up economies. Research conducted in the Bangalore region of India demonstrated that despite the existence of many enterprises, including start-ups, from high technology sectors, they lacked an effective connection with research institutions (Mungila Hillemane, 2020, pp. 1167–1185). Even greater difficulties arise in developing countries, where there is not only a lack of technological capabilities, but also of political consent for building cooperation networks (Quartey & Oguntoye, 2021, pp. 1100–1118). In addition to highlighting the differences between particular types of countries, it should also be emphasized that within individual groups (Akpinar & Qi, 2020, pp. 13–26) or within regions in one country (Liu & Huang, 2018, pp. 40–50), there may be divergences related to the functioning of the model. This is due to the different maturity levels of individual networks related to the Triple Helix model (Larsen *et al.*, 2018).

Entering network systems with a Triple Helix provides the opportunity to increase the innovative potential of economies (Brem & Radziwon, 2017, pp. 130–141). Skilful relationship-building in the system is particularly important for small and medium-sized enterprises (SMEs), which in catching-up and developing countries have not yet achieved a critical mass in networking (Fitriani *et al.*, 2019, pp. 233–248; Brink & Madsen, 2016). In developed countries, the effects of cooperation within Triple Helix for SMEs are also inconclusive. For example, cooperation with the government and enterprises in American SMEs in the green goods sector was more important for their growth than with the scientific institutes (Li *et al.*, 2018, pp. 3–14). This is due to the fact that having respected, good-quality tertiary universities and industries are a necessary, but not sufficient, requirement in building a successful Triple Helix model in the economy (Kim & Lee, 2016, pp. 33–41).

The transfer of knowledge from science to business domain is determined by the technological specificity of the countries in which enterprises are located (cf. ESPON KIT, 2012). Endogenous and creative-adaptive countries have the potential to use knowledge from inside and outside of the country. Enterprises which are emerging innovators are not able to absorb pioneering solutions and limit themselves only to creating imitative projects (Smętkowski *et al.*, 2017, p. 8), and Polish regions mostly belong to this group.

Nevertheless, there is potential to start building science-business links. Research conducted by Lejpras and Stephan (2011, pp. 543–575) showed that the proximity of local research institutes and universities is a significant factor supporting the creation and development of spin-offs, especially if it was accompanied by support from public administration and other entities whose statutory goal was supporting the innovativeness of enterprises. It should be emphasized that the innovativeness of enterprises also grows when scientific centers are not located in close proximity (Lejpras & Stephan, 2011, pp. 543–575).

The research by Lejpras and Stephan (2011, pp. 543–575) also resulted in the observation that improvement of the intensity of cooperation between scientific institutes and business entities increases the innovation activity of enterprises. The agent best-suited to coordinating such cooperation should be from within the government sphere (Brink, 2020, pp. 1–35). In catching-up countries, where entrepreneurs are reluctant to cooperate with universities, the use of government opportunities plays an important role in the transition to Triple Helix-based development. Applied support programs can initiate and accelerate such processes (Patra & Muchie, 2018, pp. 51–76; Sarpong *et al.*, 2017, pp. 142–152; Guerrero & Urbano, 2017, pp. 294–309), and can contribute to building a network of understanding. Governments can play the role of financial backers and legislators of cooperation processes, but also direct participants in innovation processes by entering into partnerships with other triple Helix entities (Mascarenhas *et al.*, 2020, pp. 316–343).

The role of scientific institutions in stimulating innovation process is important, but cooperation with other enterprises may contribute more to knowledge diffusion than collaboration with established research centres (Strand & Leydesdorff, 2013, pp. 471–484). Scientific institutions evaluate the creation of innovations without the context of monetising them. The lack of identification of a market need is even stronger, the easier it is for the scientific sphere to access public funding. Under such conditions, transaction costs in the relationship between the scientific domain and the public administration are lower than transaction costs between the scientific domain and enterprises (Nooteboom, 1999, pp. 793–805). Consequently, public funding of science domain contributes to more publications, while funding of science by the enterprises contributes to more frequent relations between the two domain and more patents (Shelton & Leydesdorff, 2012, pp. 498–511).

Poland is one of the middle-income countries catching up with Western Europe. Taking into account the above considerations, it can be assumed that Polish NIS will not be balanced and stable. There will be bottlenecks in its operation related to the transfer of knowledge from science to business. Therefore, the research hypothesis is that relationships between enterprises (suppliers, customers and competitors) support Polish NSI more than public administration and scientific institutions.

The research hypothesis requires taking into account many variables and the relationship between them and enterprises in the analysis of the national innovation system in the context of the triple helix model. Although the literature has shown that in catching-up countries, public administration and scientific institutions can contribute to the growth of innovation, the authors believe that from a systemic perspective, taking into account all the elements of the helix, their performance will be weaker than innovation processes initiated between enterprises.

Research method

Sample

The research was conducted in the form of two questionnaires in the Polish industry between 2013–2017 in accordance with the international methodological standards included in the Oslo Manual (OECD, 2005, pp. 1–164), together with the authors' own contribution. We used the private database called Teleadreson to identify companies for the survey. It includes 70.735 active manufacturing firms. We've collected 8.622 forms over the five years of the study. To keep the statistical stratification (regional structure of enterprise number) we cut off the sample to 6.284 enterprises. The response rate to the form was 12.2% (e.g. the alternative research based on National Statistical Office database with the same methodology let us get 5.5% response rate).

As Lundvall (2007, p. 105) suggests, students participating in educational programmes during the same period in which the study was conducted were involved in the research process. Our students helped us to reach each company at the first stage by making a phone call. After obtaining permission from the business owner, the survey was converted to the CAWI method.

Variables and econometric methods

The variables adopted for the study were based on the international standards for measuring innovation activity contained in the Oslo methodology (OECD, 2005, pp. 1–162).

According to the research assumptions, the dependent variables are those that depict innovation activity at the time of entry to the system and exit from the system. As a result of natural limitations, only key variables were focused on. The input to the NIS includes expenditures incurred by firms on research and development activities, i.e. technology creation (R&D_exp), and investments in new machinery and technical equipment, i.e. technology transfer (MACH_exp). The result of the output activities are innovative products (New_PROD) and technologies directly in production introduced in enterprises (New_PROC).

The variables have a nominal scale. The first one (R&D_exp) takes the value 1 for an entrepreneur who has decided to spend money on R&D and the value 0 for an entrepreneur who has not taken such a decision. For the other three dependent variables the construction is the same. These are expenditure on machinery (MACH_exp), implementation of a new product (New_PROD) and a new process (New_PROC). The situation is similar for the independent variables. All of them are dummy, where a value of 1 means that something happened and 0 means that it did not happen.

A similar situation is with independent variables. All of them are dummy ones where value 1 means that something happened or 0 that it didn't. The variables are divided into four groups. The first concerns the internal attributes of enterprises and these are usually control variables in the model, which are used to show the phenomena studied within a wider context. These include the size of enterprises (micro, small, medium, large); ownership (domestic, foreign, mixed); technological advancement (low, medium-low, medium-high, high); the economic situation (improvement, deterioration, stagnation); and sales range (local, regional, national, international). The second group of independent variables concerns sectoral conditions. These include cooperation in the field of innovation with suppliers, customers, competitors and within the capital group. They are the first constituent of the triple helix. The third group concerns science institutes. With reference to Poland, the study covers innovative cooperation with universities, departments of the Polish Academy of Sciences, foreign research centres and other R&D departments. Together, they are responsible for the second part of the system: the spiral of innovation. The last element of the system are business support organizations, which are public organizations that support enterprises at various stages of the innovation process.

The use of dummy variables for the survey simplified data collection. Respondents were not asked about the amount of expenditure incurred, but about whether such expenditure occurred. Thus, there was no need to standardize the variables. As a result, the return rate of questionnaires was much higher than in other cases, which contributed to the reliability of the data obtained.

The formal expression of the variables adopted in the study for enterprises *i* is as follows:

$$\begin{aligned} &INPUT\ (R\&D\_exp_i;\ MACH\_exp_i)\ or\ OUTPUT\ (New\_PROD_i;\ New\_PROC_i) = \\ &= \alpha_0 + \alpha_1 COOP\_sup_i + \alpha_2 COOP\_cus_i + \alpha_3 COOP\_comp_i + \\ &+\alpha_4 COOP\_group_i + \alpha_5 COOP\_univ_i + \alpha_6 COOP\_foreignS_i + \\ &+\alpha_7 COOP\_domesticS_i + \alpha_8 COOP\_pan_i + \alpha_9 SUPP\_techpark_i + \\ &+ \alpha_{10} SUPP\_techinc_i + \alpha_{11} SUPP\_techcent_i + \\ &+ \alpha_{11} SUPP\_businessangel_i + \alpha_{12} SUPP\_loanfund_i + \\ &+ \alpha_{13} SUPP\_creditfund_i + \alpha_{14} SUPP\_traincentr_i + \\ &+control\ variables + t_i + u_i \end{aligned} \tag{1}$$

The definitions of the variables expressed in the formula is given in Table 1.

According to the Oslo methodology, innovation activity should be examined in three-year periods. Since the study lasted five years, we used a time variable that was rejected in the estimation procedure (stepwise regression forward). This means that the time shift in the study periods was not relevant for the construction of the model.

Due to the qualitative nature of the dependent variables and the specifics of the research sample, multivariate logistic models were used to test the research hypothesis. The research procedure, however, was more sophisticated. Forward stepwise regression was used to remove independent variables, which are strongly correlated and do not contribute greatly to the model, from the equation in the estimation process. The Wald test and p-value were used to assess the accuracy of the models. The significance of the parameters of the independent variables was checked by standard error, Student's t-distribution and p-value. Statistica software was used for the analyses.

The presentation and interpretation of the study results included in the tables was based on the odds ratio. This is a measure specific to logistics models. The threshold value of the quotient is 1. Above this value, the chances for innovative activity are higher than in the reference group by a certain percentage. Below 1, the likelihood of innovative activity is lower. The reference variables included micro and domestic enterprises, low technology, local sales ranges, and improvement in the market situation. In the case of the remaining independent variables, some issues arose from their specific characteristics. For example, the reference group includes companies that are not exporters.

Results and discussion

A vertical analysis of conditions for NIS input and output: a preliminary interpretative model

In the process of statistical stepwise estimation, four multivariate logistic models were created. They illustrate the set of factors determining the national innovation system in Poland in the years 2013–2017, taking into account the full Triple Helix, i.e. enterprises (industry), scientific institutes and public administration. The interpretation of the results obtained will be performed vertically (each model independently) and horizontally (transformation of the input vector into the output vector of the innovation system).

The basic measure used here is the odds ratio, which details how the chances for innovative activity (in this case, expenditure on R&D, investment in new machinery, implementation of product and process innovation) are higher or lower in the surveyed community under the influence of a given condition (independent variable, e.g. cooperation with other companies).

Table 2 shows the relationship between the type of expenditure on innovation activity and the implementation of new products and technologies and cooperation with individual agents of the Triple Helix (enterprises, science institutes and public administration, i.e. business support organisations). The R&D activity (Model 1) is described most broadly with the use of external variables. This means that its shaping depends on a greater number of conditions than the other dependent variables, i.e. investment in machinery and equipment (Model 2) or the implementation of new products (Model 3) and production technologies (Model 4) that were examined. This results in greater R&D diversity and its heterogeneous nature.

Research and development (Model 1) is conducted in Poland mainly by large enterprises, with high levels of technology thanks to innovation cooperation with the national scientific institutes or with support institutions (technology transfer centres). Odds ratio values have the highest values for these variables. Other factors also have a positive effect on R&D, but their impact is weaker.

Investment decisions in equipment and machines (Model 2) are predominantly the domain of large and medium-sized enterprises, although small enterprises also make such decisions, albeit fewer of them. Strong support in this area is observed from foreign research centres (highest odds ratio value in the model), suppliers or some business-related institutions, such as training and consulting centres and technology parks. National research institutes do not have a systemic impact on this aspect of innovation activity at the entrance to the input vector.

New products (Model 3) in the domestic industry are mainly a consequence of internal efforts of enterprises with a special role of R&D or with strong support from other entities related to them by capital (technology transfer from the parent company). Innovation cooperation between suppliers and national research centres plays an important role here. Support is also observed in business-related centres, but only those connected with financial matters or with less potential for knowledge transfer, such as training and consulting centres.

New production technologies (Model 4) in Poland are, again, primarily the result of the internal activities of entrepreneurs, but currently they are mainly a consequence of the purchase of new machines and equipment. Departments of the Polish Academy of Sciences and foreign research centres are also strongly involved in the modernization of the machine parks Support is also visible from guarantee funds, technology transfer centres and technology incubators.

Determinants of transformation of the input vector into the output vector to and from the innovation system - comparative analysis of the models

The main and original element of the paper is to evaluate innovation activity in the National Innovation System from the perspective of the contribution to the system and the effects achieved taking into account all the elements of the Triple Helix (Table 2). A horizontal analysis of the variables (Table 2) allows for the assessment of the directions and forces in the process of transforming the input vector into the output vector.

The first group of variables analysed was expenditure on innovation. R&D activity is focused on creating new products in domestic industry. Entrepreneurs who run them are more than twice as likely to create new products (the odds ratio in Model 3 is 2.11). On a smaller scale, this applies to the implementation of new production technologies, where the chances of implementation increase by 51%.) Investment in buildings, which is related to the use of new technologies and investment in machinery and technical equipment mainly results in the modernization of the technology park owned (Odds ratios are higher in Model 4 than in Model 3). The purchase of software in industry is related only to the need to manufacture new products.

The technical levels of enterprises also provide interesting, but simultaneously surprising results. High-tech entities in Poland are strongly involved in R&D (138% more often than other technological groups, which is shown in Model 1), but they introduce new products only 40% more often (Model 3), while the interest in changes in production technology decreases by 40% (Model 4). This is in line with the research by Hirsch-Kreinsen *et al.* (2006, p. 17), who found that in countries with a traditional industrial structure, high R&D expenditure positively affects product innovations, but at the same time reduces the number of technological innovations. Unfortunately, this is an effect of substitution, i.e. the displacement of technological changes by research and development, which will have certain consequences in the future.

Enterprises from the group of medium-high technologies are 50% more likely to conduct R&D activities (Model 1) and at the same time invest in new machinery 23% more often (Model 2) than companies of other sizes. Unfortunately, which has resulted in a 28% reduction in commitment to production modernization (Model 4), which, in turn, does not match the conclusions of Hirsch-Kreinsen *et al.* (2006, p. 18). A possible reason for this type of divergence may be the time lag between inputs and outcomes, but rather it argue that this type of divergence is a result of limiting innovation activity in this group of enterprises, which is unexpected and dangerous in the long run, given the technological potential and the evolutionary need to develop the technological competences of modern industries. Perhaps this is the result of the lack of systemic support for this group of enterprises with state policy instruments and, as a consequence, results in unused technological development opportunities, which will be difficult to compensate for.

In the case of enterprises from the group of medium-low technologies, innovation activity on the expenditure side (Model 1 and 2) is significant, although still weak, and ultimately this is not reflected in the effects (no odds ratio meeting the conditions for statistical significance in Models 3 and 4). The main conclusion related to the levels of technology is the thesis that industrial enterprises in Poland are too poorly differentiated in terms of technology (they have high homogeneity). Technological advancement is not a systemic circumstance for differentiating innovation policy. Research must continue in order to discover possible explanations for this. Possibly, the explanation for the weakly technologically-advanced enterprises or the strong ones in the area of low technologies is a consequence of many years of supporting entities from the area of low and medium-low technologies, which has distorted the system. The conclusions of the research by Hirsch-Kreinsen *et al.* (2006, pp. 3–21) may be relevant here. They claim that the effectiveness of investments in R&D in national systems depends on the balance and the relations between low and high-technology enterprises. A small number of connections between these groups of industries shows appropriate and healthy relations in the system (Robertson & Patel, 2007, pp. 708–721), i.e. they follow their own, clearly defined, other technological paths adequate for their level. However, this balance is upset in Poland. The high technological homogeneity of the system shows that there are too many relationships between traditional and modern industries, which limits the possibilities for the development of the latter. Innovation in the medium-high technologies and high technology systems offers unlimited possibilities, but requires capital, knowledge (internal and external) and high potential demand, which is associated with the need to internationalize them (Nowiński & Rialp, 2013, pp. 191–231; Andersson *et al.*, 2014, pp. 390–405). Low-tech enterprises, in contrast, look more often for external technological knowledge that favours cooperation, communication and interaction between enterprises in a limited space (Wu & Wang, 2017, pp. 488–502), i.e. they more often co-create a local innovation environment.

Exporters are an important part of the national innovation system. It is true that their positive impact is not high compared to other circumstances in the models, but at the same time they conduct R&D 54% more often (Model 1) and buy new machines or devices 21% more often (Model 2), which in turn leads to the acceleration of 20% in the implementation of new products (Model 3) in foreign markets.

Despite export activity of high-tech enterprises in Poland still being relatively low, operating in foreign markets should clearly stimulate innovation activity. This applies to all industries, but most particularly the most advanced ones (Mińska-Struzik, 2015, pp. 139–162).

The size of enterprises has traditionally been a strong determinant of input and output innovation activity. Small and medium-sized entities behave similarly i.e. they are both involved in R&D (with levels of 38% and 86% more often, model 1) and investment activities (by 42% and 66%, model 2), and the results achieved are limited only to new products (model 3). However, large entities are more than twice as likely to conduct research (model 1) and buy new machines and devices 76% more often (model 2). However, they achieve the effects only on the side of new production technologies, with chances higher by 27% compared to other entities (model 4).

In the group of factors describing the market situation, "economic upturn" was adopted as the reference variable. A consequence of formulating the variable in this way is that the odds ratios assume values below one. This is because the variables included in the models explain the deteriorating market situation or the lack of its changes. Both circumstances are strongly unfavourable for conducting innovation activity in any form (Model 1, 2, 3 and 4), which is in line with the observations made by Lamey (2012, p. 16) and Archibugi (2013, pp. 1247–1260). A prerequisite, therefore, is a permanent and time-stable improvement in the economic situation, even at a moderate level. Entrepreneurs react most strongly in terms of decisions related to R&D activities (Model 1) — limiting this activity by 45% in the event of stagnation and by 59% when the economic situation deteriorates. This behaviour also applies to investment decisions to a lesser extent (model 2) — a decrease of 32% and 40% respectively, although these levels are still high. The reactions on the side of implementing new products (model 3) and technological processes (Model 4) are weaker but similar — with closing decreases of 17%–27%. Once again, the reactivity of the system at the output is weaker than at the input. The results obtained support the conclusions of Tomaszewski and Świadek (2017, pp. 1896–1913), according to which in Central and Eastern and Southern European countries, a pro-cyclical approach to innovative activity is dominant.

Another large group of determinants of National Innovation System is the cooperation of industry in the area of innovation with scientific and sectoral organizations. Joint research work carried out with universities and other research institutes is the strongest determinant of the national system (Model 1 and 2), with transformation only towards new products (Model 3). The data of the Central Statistical Office (Główny Urząd Statystyczny, 2016, p. 106) and PricewaterhouseCoopers (Tylman, 2015, p. 21) also indicates the dominant role of universities and research institutes. Unfortunately, there is no link between this process and passive technology transfer. In other words, R&D is carried out in isolation without parallel modernization of the production technology, i.e. the so-called fast path of progress, effective in the short term. The Polish Academy of Sciences (PAN) departments, although slightly less important, twice as often encourage enterprises to engage in R&D activities (Model 1), with effects on the side of production technology (Model 4) — a long path of progress, but with greater potential. Moreover, the effectiveness of the transformation of R&D in new solutions is higher on the part of PAN departments than on the part of universities. Unfortunately, these departments also focus on research activity without the support of passive technology transfer. Foreign research centres also play an important role in shaping the national innovation system. Their impact on R&D in enterprises is slightly lower, but with the parallel combination of processes of generating knowledge and transferring it to industry. The impact of these two channels is similar, and, as a consequence, changes in production technologies are 67% more frequent (Model 4). Attention is drawn to three different mechanisms of the influence of scientific institutes on innovation processes in Poland. The first is the transformation of R&D into new products (universities). The second is research activity focused on changes in production technology (PAN). The third is the simultaneous use of R&D and the transfer of passive technologies to achieve progress in the machine park (foreign science centres). Thus, a strong differentiation of the impact in the innovation system is noticeable. The results obtained here complement and extend the conclusions of the research by Broström and Lööf (2006), who emphasized that cooperation with universities influences the occurrence of improving, not pioneering, innovations.

Vertical and horizontal connections of enterprises with suppliers, recipients and within the capital group are the second area of innovation cooperation complementing science. It turns out that the vertical supply chain up and down is the most durable element of the innovation system in Poland, which is also confirmed by research conducted by employees of the University of Lodz (Adamik, 2013, p. 32). There is an acceleration of the transformation of R&D (model 1) and the purchase of machinery and equipment (Model 2) in new products (Model 3) and production technologies (Model 4), with a stronger influence of suppliers on these processes. Thus, the question arises: is a strong, but localized impact more important for systemic effectiveness, or is it weaker, but more permanent? This question cannot be answered at present, but it is an interesting research problem. Suppliers double the industry involvement in research activities (Model 1) and contribute 55% to the purchase of new machinery (Model 2). The result of these activities is that new products are produced twice as often (Model 3) and new production technologies are initiated 44% more often (Model 4). In this respect, the results obtained confirm the conclusions of the research carried out by Glabiszewski and Sudolska (2009, pp. 17–18) and Kruczek and Żebrucki (2011, pp. 364–365) concerning the goals and motives for establishing cooperation among the participants of the supply network.

However, the impact of recipients on the innovation activity of enterprises is weaker, particularly at input (model 1 and 2) and output (model 4). This is in contrast to the research carried out by Lettl *et al.* (2006, pp. 251–272), Jeppesen and Molina (2003, pp. 363–383), Raasch *et al.* (2008, pp. 482–498) and Fuller *et al.* (2007, pp. 60–71), whose research indicates that cooperation with recipients is the key to adjusting the product to the requirements of sophisticated and highly professional recipients related to, extreme sports, health care and computer games. The innovation system in Poland is not ready to face such challenges.

Enterprises that are part of the capital group have their own unique characteristics. These include the quick and effective ability to produce goods (Model 3) shortly after establishing a production line (Model 2).

It is also worth mentioning that the Polish industrial system lacks significant horizontal relations with competitors. This results in little or no increases in innovative activity (lack of odds ratios meeting the conditions for statistical significance). In this respect, Polish enterprises differ from the model implemented by both global concerns and enterprises operating in highly developed countries (Gnyawali & Park 2011, p. 1; Bengtsson & Kock 2000, p. 414; Poznańska, 2009, pp. 397–400).

The last group of the independent variables that were analyzed is business support organizations, which are the third element of a technological transformation system. They are a significant and strong complement to the NIS, despite the relatively short period of operation in the market. Their intensive development lasted for decades, but has slowed significantly in the last twenty years.

In the context of R&D, all business support organizations contributed to supporting industry (Model 1, 2, 3 and 4). This is in line with research conducted in South Korea (Lee *et al.*, 2020). It has been demonstrated that the intensity of R&D works in both the long-term and the short-term increases after cooperation with public entities is established. In this context, the fact that the Polish economy does not differ from developed economies is a positive phenomenon. Unfortunately, in the case of innovation centers in the remaining input and output elements which were analysed, the situation is no longer clearly positive. Technology parks and incubators contribute to the costs of purchasing new machinery and equipment (increase in opportunities of 76% and 62%, model 2), though none of the institutions analysed influenced the creation of product innovations (lack of odds ratios meeting the conditions for statistical significance). This is in contrast to the research conducted so far, which has shown that technology parks (Diez-Vial & Fernandez-Olmos, 2015, pp. 70–84; Vasquez-Urriago *et al.*, 2014, pp. 835–873) and incubators (Sedita *et al.*, 2019, pp. 439–454; Marques *et al.*, 2019, pp. 153–169; Mansano & Pereira, 2016, pp. 23–32; Apa *et al.*, 2017, pp. 198–221) increase the chances of creating product innovations. Furthermore, earlier analyses conducted in Poland (Gorączkowska 2020, pp. 799–817; Gorączkowska, 2015, pp. 137–156) indicate that these institutions determine the implementation of new products. The impact force is not large, although it is statistically significant, which is a consequence of taking into account other elements of the Triple Helix model in the analyses. This means that innovation centers have a positive impact on the Polish economy, but the impact of other factors included in the model is much greater than that of the innovation centers themselves.

In Polish conditions (similar to Turkey), however, research indicates that technology parks contribute to the implementation of new technological processes (Ar & Baki, 2011, pp. 172–206). This type of innovative activity is also supported by technology incubators and technology transfer centers (Model 4). It is concerning that the conditions of statistical significance were not met by academic business incubators. In this context, it can be argued that this state of affairs indicates the low maturity of this type of organisation and the low potential of universities in generating business ideas.

Business angel networks are a relatively new form of supporting venture capital projects in Poland. Their impact on the industry is visible only at the entrance — R&D intensification by 61% (Model 1). This may be due to the activity of business angels being of an emerging nature, and not well developed (Prohorovs *et al.*, 2019, pp. 2868–2880). As a result of the comparatively small number of angel investors / angel networks, their impact is incidental and not systemic.

The most interesting types of organizations, however, are those with less knowledge transfer potential. These include local or regional loan and guarantee funds as well as training and consulting centres. They are involved in all stages of the input and output innovation process. Despite the weaker impact of the first two on entry and exit (there is a smaller odds ratios than in the case of innovation centres, Model 1, 2, 3 and 4), training and consulting centers achieve effects comparable to the impact of technology parks and incubators or technology transfer centres. The question is, therefore, how can institutions with a low potential for knowledge transfer have such a significant impact on innovation activity? First, the impact of innovation centres is weaker than expected. Second, the technological maturity of enterprises, their needs and existing limitations are not mature and sophisticated, but rather depend on financial support and involve the transfer of less advanced knowledge. Third, entrepreneurs look for more diverse mechanisms supporting innovation, such as cooperation with other enterprises (Ahn *et al.*, 2020).

Conclusions

The meaning of Triple Helix agents in the Polish innovation system is varied. First, the innovative performance of enterprises is primarily a consequence of their internal engagement in these process. The system as a whole does not act strongly enough. R&D results in the new product, while other activities result in new technologies. This rule does not apply to foreign research institutes who are engage in both solutions. This is in line with the studies by Hirsch-Kreinsen *et al.*, (2006, p. 17). However, a substitution effect may be occurring here, i.e. the removing the technological progress from production to the new product, which could be dangerous in the long term.

Second, establishing cooperation between enterprises and various Triple Helix actors increases the chances of innovation as in Spain (Hernandez-Trasobares & Murillo-Luna, 2020), but not with everyone and not to the same strength. The scientific institutes and innovation centers have a strong, but point-like impact. Suppliers, customers and financial support centers have a slightly weaker influence but in many places of the system what could be more important from the strategic point of view. A question that arises at this stage is "what is more favourable to the system?", Taking into account the innovation results in the analysis, it required to learn more about the durability of the impact along the subsequent stages of the innovative process is more favourable than a stronger but more localised one is. The achieved effects are higher and concern both products and technologies. In this respect, suppliers are the most effective factor in the innovation system.

Third, the economic situation has a strong impact on the effectiveness of innovation processes. What is especially important is that both economic stagnation and a crisis are negatively and similarly correlated with levels of innovation activity. There is, therefore, an imperative to maintain sustained economic growth even if it is only at a low level, otherwise the innovation project could be interrupted or spread out in time.

Fourth, the technological results are significantly lower than the expenditures, which seems logical, because not all innovation projects are successful. However, the authors have not found similar conclusions elsewhere in the literature, which makes comparison difficult.

In the light of the above conclusions, it can be unambiguously stated that the aim of the study has been achieved. It was established which elements of the Triple Helix (in the study they had the form of variables that met conditions of the statistical significance) and with what strength (based on odds ratios) they influence the functioning of the National Innovation

System. In general, it can be assumed that the influence of individual Triple Helix elements is positive (research question 1), but its strength and quality are varied (research question 2). The strongest influence on NIS is exerted by scientific institutions, but this influence is punctual and non-systemic. The effectiveness of the impact of the scientific domain on the growth of innovation activity of enterprises relates only to the stimulation of R&D expenditure. In its case, no stable impact has been noted, i.e. on all areas of inputs and outputs. Foreign research centres, which offer a more integrated offer combined with transfer of ready technologies, are a positive exception here. A similar situation exists in the case of business support organisations. Industrial enterprises receive support from business support organisations, although in a heterogeneous form. The most stable are financing funds Innovation centres focus on research and development activities, but the results of their activities can be seen in production processes — this is an impact with greater potential. A higher frequency of relations, but also a weaker intensity, is found in the case of cooperation between enterprises, with particular emphasis on suppliers and customers. They constitute a strong and stable support for the National Innovation System in Poland, with a special role of the first ones. Unfortunately, relations with competitors do not determine in any direction the technological activity in the system (research question 3).

The research hypothesis set after the literature review has been partially confirmed. Relations between enterprises (suppliers and customers) support the Polish National Innovation System to a greater extent than public administration and scientific institutions. The odds ratios are similar between them or even a little bit lower but cooperation with supplier happens for 31.5% firms and with customers for 20.9% compares to university — 5.2% or other research institutes — 3.1%. Besides supplier cooperates with firms at every step of innovation process and others are at single step only. The hypothesis was not confirmed with regard to cooperation with competitors. These companies did not determine NIS in any way.

The limitations of the study relate to the data used. They are purely binary. Using primary data from, for example, the National Office of Statistics would allow for more accurate models as would taking into account the flexibility of entrepreneurs' decisions. It is difficult to clearly define whether the durability of the impact or its strength are the key for the effectiveness of the innovation system. The odds ratio is not the only measure which should be taken into account to describe any NIS. The other is the percentage share of each innovation phenomenon. Both of them give us the more accurate picture of the innovation system.

The analyses conducted have also opened up potential directions for future research. First, it seems interesting whether combining interactions within a Triple Helix further stimulates innovation activity, i.e. if firms collaborate with two or three elements of the helix at the same time, are they more likely to engage in innovation activity than if they collaborate with only one? The study did not include such a variable in the analyses, but it would give an answer to the question of whether there are substitution or crowding-out effects between elements of the helix. Secondly, repeating the study in the second period would allow the analyses to take into account the possibility of a shift in time between the input and output vectors. R&D expenditures or investments in machinery may only reveal themselves in the form of new products and processes at a later stage.

The findings of the study could be of use by decision-makers who are responsible for creating a framework for innovation policy because its suggest that in catching-up countries, relying on models that have been implemented in developed countries without taking into account the technology gap may not be successful. Despite the great success of the Triple Helix model in developed economies, there are many weaknesses in its implementation in Poland.

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Annex

Table 1. Definition of the variables of the input/output equation

Variables	Description
Dependent Variable	
R&D_exp	Nominal variable; 0: lack of R&D activity; 1: R&D active (NIS-INPUT)
MACH_exp	Nominal variable; 0: lack of machinery purchase; 1: decision to purchase the new machinery (NIS-INPUT)
New_PROD	Nominal variable; 0: lack of new product; 1: the new product implementation (NIS-OUTPUT)
New_PROC	Nominal variable; 0: lack of new technology; 1: the new technology implementation (NIS-OUTPUT)
Independent Variables	
Sectoral and Science Cooperation	
COOP_sup	Dummy variable; 1: inn. cooperation with supplier; 0: otherwise
COOP_cus	Dummy variable; 1: inn. cooperation with customer; 0: otherwise
COOP_com	Dummy variable; 1: inn. cooperation with competitor; 0: otherwise
COOP_pan	Dummy variable; 1: inn. cooperation with Polish Science Academy; 0: otherwise
COOP_univ	Dummy variable; 1: inn. cooperation with university; 0: otherwise
COOP_domesticS	Dummy variable; 1: innovation cooperation with other domestic science unit; 0: otherwise
COOP_foreignS	Dummy variable; 1: inn. cooperation with foreign science unit; 0: otherwise
COOP_group	Dummy variable; 1: inn cooperation within capital group; 0: otherwise
Support system	
SUPP_techpark	Dummy variable; 1: cooperation with technology park; 0: otherwise
SUPP_techinc	Dummy variable; 1: cooperation with technology incubator; 0: otherwise
SUPP_techcent	Dummy variable; 1: cooperation with technology transfer centre; 0: otherwise
SUPP_businessangel	Dummy variable; 1: cooperation with business angel; 0: otherwise
SUPP_loanfund	Dummy variable; 1: cooperation with local or regional loan fund; 0: otherwise
SUPP_creditfund	Dummy variable; 1: cooperation with credit guarantee fund; 0: otherwise
SUPP_traincentr	Dummy variable; 1: cooperation with training and consulting centre; 0: otherwise

Table 1. Continued

Variables	Description
Control Variables	
SmallF	Dummy variable; 1: small firm; 0: otherwise
MediumF	Dummy variable; 1: medium firm; 0: otherwise
LargeF	Dummy variable; 1: large firm; 0: otherwise
MixedCAP	Dummy variable; 1: mixed capital firm; 0: otherwise
MLowTECH	Dummy variable; 1: medium-low tech firm; 0: otherwise
MHighTEC	Dummy variable; 1: medium-high tech firm; 0: otherwise
HighTECH	Dummy variable; 1: high-tech firm; 0: otherwise
ECON_drop	Dummy variable; 1: economy recession; 0: otherwise
ECON_stag	Dummy variable; 1: economy stagnation; 0: otherwise
RANGE_dom	Dummy variable; 1: domestic sales range; 0: otherwise
RANGE_exp	Dummy variable; 1: exporting firm; 0: otherwise
t	Time variable

Source: own study based on Oslo methodology.

Table 2. The value of the odds ratio for input into the system and output from the system in industry in Poland influenced by selected factors in 2013–2017 — logit modelling

Independent variables	**Odds ratio**			
	Input into the system		**Output from the system**	
	R&D_exp (model 1)	**MACH_exp (model 2)**	**New_PROD (model 3)**	**New_PROC (model 4)**
R&D_exp	x	x	2.11 (***)	1.51 (***)
BUIL_exp	x	x	1.60 (***)	1.87 (***)
MACH_exp	x	x	1.71 (***)	2.24 (***)
SOFT_exp	x	x	1.67 (***)	-
MLowTECH	1.14 (*)	1.24 (***)	-	-
MHighTEC	1.50 (***)	1.23 (***)	-	0.71 (***)
HighTECH	2.38 (***)	-	1.40 (**)	0.60 (***)
SmallF	1.38 (***)	1.42 (***)	1.18 (**)	-
MediumF	1.86 (***)	1.66 (***)	1.24 (**)	-
LargeF	3.07 (***)	1.76 (***)	-	1.,27 (*)
MixedCAP	1.27 (*)	-	-	-
ECON_drop	0.41 (***)	0.60 (***)	0.81 (**)	0.78 (***)

Table 2. Continued

Independent variables	Odds ratio			
	Input into the system		Output from the system	
	R&D_exp (model 1)	**MACH_exp (model 2)**	**New_PROD (model 3)**	**New_PROC (model 4)**
ECON_stag	0.55 (***)	0.68 (***)	0.73 (***)	0.77 (***)
RANGE_dom	1.36 (***)	-	-	-
RANGE_exp	1.54 (***)	1.21 (***)	1.20 (***)	-
COOP_sup	2.05 (***)	1.55 (***)	2.17 (***)	1.44 (***)
COOP_pan	2.16 (**)	-	-	1.82 (**)
COOP_univ	2.70 (***)	-	1.69 (***)	-
COOP_domesticS	2.25 (***)	-	1.53 (*)	-
COOP_foreignS	1.89 (**)	2.07 (**)	-	1.67 (*)
COOP_cus	1.46 (***)	1.29 (***)	1.49 (***)	1.39 (***)
COOP_group	-	1.46 (**)	2.46 (***)	-
SUPP_techpark	1.76 (***)	1.76 (***)	-	1.44 (***)
SUPP_techinc	1.77 (**)	1.62 (**)	-	1.65 (**)
SUPP_techcent	2.17 (***)	-	-	1.70 (***)
SUPP_business angel	1.61 (*)	-	-	-
SUPP_loanfund	1.30 (***)	1.54 (***)	1.35 (***)	1.42 (***)
SUPP_creditfund	1.36 (***)	1.47 (***)	1.38 (***)	1.70 (***)
SUPP_traincentr	1.82 (***)	1.77 (***)	1.48 (***)	1.59 (***)
Constants	0.16 (***)	0.83 (***)	1.17 (**)	0.29 (***)
Sample	6284	6284	6284	6284
Likelihood ratio	-3255	-3818	-3413	-3710
chi-square	1559.6	719.9	1528.4	1274.2
p-value	0.00	0.00	0.00	0.00
R^2 *Cox-Snell*	0.22	0.11	0.21	0.21
R^2 *Nagelkerke*	0.30	0.15	0.28	0.29

Note: (***) – statistical significance at 1%, (**) – statistical significance at 5%, (*) – statistical significance at 10%.
The sign "-" means rejection of the variable in the process of stepwise estimation of the model.