



The Role of Regional Intangible Assets for the Innovation Activity of Enterprises: The case of Polish Regions

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Abstract

Innovative enterprises may undertake innovation activity in the form of research and development (R&D) or the acquisition of already developed technology (imitative innovation). Both types of innovation may influence economic growth or catching-up processes in different ways. Therefore, in the research presented, various types of innovation activity are analysed based on Community Innovation Survey data. The question is how the regional environment, characterised based on the data on intangible assets, affects R&D activity and the acquisition of machinery and software. The analysis was conducted for the years 2004–2014 in 16 Polish regions. Intangible assets were measured using the intellectual capital index. Panel data econometric models were applied to test the relations between various types of innovation activity and intangible assets in the regions. Human capital was found to be positively related to internal and external R&D activity. Life-long learning (one of the human capital indicators) was found to be positively related to the acquisition of machinery and software. Structural capital was found to be positively related to internal and external R&D activity.

Keywords Innovations · Intangible assets · Intellectual capital · Regional development

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Introduction

Innovations are seen as the main determinant of long-term economic growth (Abramowitz, 1956; Solow, 1956, 1957). Segerstrom (1991) points out that the effects of public support for research and development (R&D) based innovations (developed based on internal or external R&D) can differ from support for imitative innovations¹ (based on the acquisition of existing technology and knowledge). Hu et al. (2005) show that the productivity of companies increases only in the case of the technology transfer associated with internal R&D activity. These results, in turn, are consistent with previous findings, proving that internal R&D activity increases the absorption capacity of new knowledge and new technologies (Cohen & Levinthal, 1989).

Meanwhile, the countries of Central and Eastern Europe, which joined the European Union (EU) in 2004 (10 NMS), are characterised by low expenditure on R&D activities. From 2000 to 2017, these countries were characterised by a level of total R&D expenditure (as a percentage of GDP) lower than the EU average (the GERD² for the EU-27 countries was 1.77% in 2000, and 2.07% in 2017). In addition, it turns out that the model of innovative activity in the countries of Central and Eastern Europe is imitative; the dominant way of modernising economies is investing in the purchase of machinery, equipment and software, which allows the purchase of already developed technology without the need to conduct costly R&D activities. In the years 2004–2014, innovative enterprises in the EU-15 countries were characterised by a similar involvement in internal R&D activities and in the purchase of machinery and software. On the other hand, in the 10 NMS, the dominant form of activity was the purchase of machinery, equipment and software. The lowest level of involvement in internal R&D activities was observed in Poland – on average, 31% of innovative enterprises. On the other hand in Poland was the highest level of involvement in the purchase of machinery, equipment and software – 90% in 2004 and 73% in 2014 (Lubacha, 2021).

The question which arises is if a regional variety of innovation activity can be observed in Poland? Regions characterised by the imitative way of implementing innovations, and regions where the transfer of already developed technology from outside dominates, need different ways to support innovation activity and different innovation policies (Pater & Lewandowska, 2015; Capello & Lenzi, 2014; Capello & Lenzi, 2013; Vale, 2011). The main aim of the conducted research is to identify the patterns of innovation activities undertaken by innovative enterprises in Polish regions and to identify the factors of a given type of innovation activity. Innovation activities include both R&D and non-R&D activities (e.g., the acquisition of additional external knowledge, the acquisition of machinery, equipment and other capital goods, training) (OECD & Eurostat, 2005). Martin (2013) points out that in the research conducted so far, the main measure of innovation was internal R&D and patenting, but these indicators do not cover other types of innovative activities. To

¹ It is now recognised that the imitation of an innovation applied by someone else to the market is treated as an innovation if it is the first time in a given enterprise (OECD, Eurostat, 2005, pp. 46).

² GERD - Gross domestic expenditure on R&D

fill this gap, the conducted research also covers, apart from analysis of the data on internal R&D activity, other types of innovative activities, such as the acquisition of machinery and equipment or that of knowledge. According to previous research Poland and Polish regions are far behind the European one in terms of innovativeness (Szajt, 2020; Sobczak & Głuszczyk, 2018). Lubacha (2020) distinguished four types of Regional Innovation Systems in Poland: (1) public R&D based regions; (2) imitative regions, (3) private R&D based regions, (4) diversified innovation activity regions. Arendt and Grabowski (2019) found that in less-developed regions firm-level capabilities are more important than regional factors.

Intangible assets (human capital, social capital) are frequently analysed in regional-level research concerning innovations and innovation capacity (eg. Broekel & Brenner, 2011; Casadella & Uzunidis, 2021; Capello et al. 2012; Gancarczyk et al., 2020; Mackiewicz et al., 2009; Wziętek-Kubiak & Pęczkowski, 2021). Research into the intellectual capital (IC) of companies (Edvinsson & Malone, 1997; Roos & Roos, 1997), as well as at national (Edvinsson & Stenfelt, 1999; Bonitis, 2004) or regional (Schiuma et al., 2008; Więziak-Białowolska, 2010; Wosiek, 2012; Mikic et al., 2021) levels, is an attempt to measure intangible assets in a more comprehensive way. Since IC is a complex phenomenon, it can be measured as a composite indicator (OECD, 2008). Lin and Edvinsson (2020) underlined a need to conduct research on IC at regional and national levels, and on the relation between IC and its results (innovation, value creation, etc.)

In the presented research, the IC of 16 Polish regions is measured. Moreover, the relation between intangible assets in the regions and various types of innovation activity is examined. To examine the relation between the elements of IC (human capital, social capital, structural capital) and the engagement of innovative enterprises with innovation activity, estimation of the econometric panel models for the selected variables was performed. The analysis was conducted for the years 2004–2014 in 16 Polish regions.

In Section [Theoretical Framework](#), the theoretical framework for innovation activity and IC are discussed. In Section [Data and Methods](#), the data and method used in the analysis are presented. Section [Results](#) is devoted to discussing the most important observations, and Section [Conclusions](#) contains the conclusions and summary notes.

Theoretical Framework

Innovations implemented by an enterprise are the result of innovation activities. According to the Oslo Manual (OECD & Eurostat, 2005, p. 18), “innovative activities include all activities of a scientific, technical, organizational, financial and commercial nature that actually lead or are intended to lead to the implementation of innovation”. Innovative activities include both R&D activities and other innovative activities (OECD & Eurostat, 2005). Other innovative activities include activities that do not fall within the scope of R&D, but are part of innovation, inter alia: relations with users; competition monitoring; using consulting services; the purchase of technical information; the purchase of know-how and skills in the form of services;

skills development through training; hiring new people; knowledge transfer through learning; the purchase of hardware, software, and the means of production containing the effects of the innovative activities of other companies (OECD & Eurostat, 2005, pp. 35-36).

Including both forms of innovative activity in the research – R&D activity and the purchase of machinery, devices and software – seems important due to the consequences of supporting the development of innovation by the state. Davidson and Segerstrom (1998) prove on theoretical grounds that only state subsidies for innovative R&D activities lead to faster economic growth. On the other hand, support for imitative R&D activity slows down growth. In turn, Griffith et al. (2004) show that the sectors of the economy lagging behind in terms of productivity reach the productivity frontier especially quickly if they invest significantly in R&D. Martin (2013) points out that in the research conducted so far, the main measure of innovation was internal R&D and patenting, but these indicators do not cover other types of innovative activities. The use of the data on patent applications is justified by the wide availability of the data and its comparability between countries. However, an invention is not the same as an innovation, thus technology protected by a patent is not always implemented in the form of an innovation. The data from the Community Innovation Survey (CIS³) used in this study, which is carried out in selected EU countries using a standardised form, make it possible to analyse innovative activities carried out by enterprises that actually apply innovations. At the same time, one should be aware of the limitations of survey research, such as the subjectivity of the data obtained and the adaptation of the form in subsequent editions of the survey (Mairesse & Mohnen, 2010).

Innovative processes are geographically localised, and territorial features are reflected, among others, in the technological systems, production processes, manufacturing organisation, social and political surroundings. Also, some of the factors of innovation, such as tacit knowledge or institutions, are immobile to some extent (Todtling & Trippl, 2011; Nauwelaers, 2011; Cook & Morgan, 1998). Regional Innovation System concept underlined the role of regional assets, and role of interaction between regional actors in generation and diffusion of innovation (Doloreux & Parto, 2004; Evangelista et al., 2002). Intangible assets measured as IC may affect the level of innovation activity in regions (Mikic et al., 2021; Schiuma & Lerro, 2010). IC is a term that originated within the field of microeconomic research as a way to measure the intangible assets of a company (e.g., Edvinsson & Malone, 1997; Roos & Roos, 1997). Later the IC concept was implemented in research at national (cited in Edvinsson & Stenfelt, 1999; Bontis, 2004) and regional levels (Schiuma et al., 2008; Więziak-Białowolska, 2010; Wosiek, 2012). Bontis (2004) modified Edvinsson and Malone's model (Edvinsson & Malone, 1997), and defined IC as the “hidden values of individuals, enterprises, institutions, communities and regions that are the current and potential sources for

³ Data from the CIS were delivered by the Polish National Statistical Office (GUS) in the form of aggregated data at the NUTS-2 level. The acquisition of the data was financed by the National Science Centre, Poland, grant no. 2016/21/N/HS4/02098

wealth creation” (Bontis, 2004, p. 14). In regional-level research (Schiuma et al., 2008; Więziak-Białowolska, 2010; Wosiek, 2012), it has been emphasised that the main component of IC is human capital and that the remaining forms of capital (social, structural, relational, and development) play a supporting role for the further development of human capital and help to transfer knowledge and competencies into economic results.

Mincer (1958), Schultz (1960) and Becker (1975) developed human capital theory. In a broader sense, “human capital refers to the knowledge, information, ideas, skills, and health of individuals” (Becker, 2002, p. 3). The social capital theory was developed in sociology in the 1980s (Bourdieu, 1986; Coleman, 1990). According to Putnam’s definition (Putnam, 1995, p. 67), “social capital refers to features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit”. Three components of social capital may be distinguished: social trust, norms, networks (Putnam et al., 1993). Structural capital in IC research is defined in comparison to human capital: “It has come to view intellectual capital as both what is in the heads of employees (‘human capital’) and what is left in the organisation when people go home in the evening (‘structural capital’)” (Roos & Roos, 1997, p. 8). In the Bontis’ model (Bontis, 2004, p. 21), structural capital was defined as “the non-human storehouses of knowledge in a nation which are embedded in its technological, information and communications systems as represented by its hardware, software, databases, laboratories and organizational structures which sustain and externalize the output of human capital”.

In this study, IC is understood as the totality of resources that are not directly observable. IC comprises a set of components in the form of human capital and its “instrumentation” (social capital, structural capital) necessary for translating knowledge and competencies into tangible economic results (Wosiek, 2012). Human capital is defined using Becker’s (2002) broad definition, and for social capital, Putnam’s (1995) understanding of the term is adopted in this analysis. Structural capital is defined according to Bontis (2004).

In previous research, human capital was found to be positively related to the level of innovation in regions (eg. Diebolt & Hippe, 2019; Kiuru & Inkinen, 2017; Felsenstein, 2015; Capello & Lenzi, 2015; Naz et al., 2015; Broekel & Brenner, 2011; Mukim, 2012; Lee et al., 2010; Chi & Qian, 2010). A higher level of innovation was observed in regions with a higher number of ICT specialists, specialists working in the R&D sector, and artists (Kiuru & Inkinen, 2017). The use of various indicators for human capital (education level, Bohemian Index, R&D personnel, etc.) did not alter the result (Lee et al., 2010; Chi & Qian, 2010). Nevertheless, innovation activities aimed at introducing new products require a balanced mix of R&D and human capital, while innovation activities for introducing new processes appear to be more dependent on the level of human capital (Capello & Lenzi, 2015). Previous research (eg. Tura & Harmaakorpi, 2010; Laursen et al., 2012; Kaasa, 2009) has underlined the importance of social capital in the regional innovation environment. The impact of social capital on innovation processes in a region is significant and comparable to the importance of human capital. However, not all forms of social capital have a similar explanatory value. Associating in organisations is one of the main driving forces behind patent activity (Hauser et al., 2007). Furthermore, a strong interaction between human capital and social capital in

the production of knowledge was indicated, while the complementarity of social capital with R&D activity seems less clear-cut (Miguélez et al., 2011). Structural capital, as in access to the internet and dense railway networks, was found to increase innovations in regions and countries (Yang et al., 2021; Xu et al., 2019). Access to the internet decreases the cost of knowledge and information diffusion (Xu et al., 2019).

As presented above, the components of IC (human capital, social capital, structural capital) are seen as important factors for innovation activity. However, as expressed in the literature review, the various types of innovation activity have different impacts on economic development. Therefore, in this research, the relation between intangible assets in the regions and various types of innovation activity is analysed. Based upon the theoretical consideration presented, the following hypotheses are set out in the research:

H1: A higher level of human capital is positively related to the engagement of innovative enterprises in R&D activity.

H2: A higher level of human capital is negatively related to the engagement of innovative enterprises in the acquisition of machinery and equipment.

H3: A higher level of social capital is positively related to the engagement of innovative enterprises in R&D activity.

H4: A higher level of structural capital is positively related to the engagement of innovative enterprises in both R&D activity and the acquisition of machinery and equipment.

H5: A higher level of social capital is negatively related to the engagement of innovative enterprises in the acquisition of machinery and equipment.

Data and Methods

According to the OECD (2008, p. 13), the “composite indicator is formed when individual indicators are compiled into a single index on the basis of an underlying model. The composite indicator should ideally measure multidimensional concepts which cannot be captured by a single indicator, e.g., competitiveness, industrialisation, sustainability, etc”. The proposed list of indicators (Table 1) was prepared while taking into account previous research on human capital (e.g., Folloni & Vitadini, 2009; Vogel, 2015), social capital (e.g., Narayan & Cassidy, 2001; Paldam, 2000), and structural capital (Schiuma et al., 2008; Więziak-Białowolska, 2010; Wosiek, 2012).

All data was normalised according to the Min-Max normalisation formula (Nardo et al., 2005, p. 48):

$$I_{qr}^t = \frac{x_{qr}^t - \min_r(x_q^t)}{\max_r(x_q^t) - \min_r(x_q^t)} \quad (1)$$

Table 1 Indicators of the Intellectual Capital Index and data availability

IC subindex	Indicator (abbreviation)	Basic data name/label	Data source [indicator code]
Human Capital (HC)	Knowledge.1 (K1)	% of population aged 25–64 with tertiary education (levels 5–8)	Eurostat [edat_lfse_04]
	Knowledge.2 (K2)	% of population taking part in education and training	Eurostat [trng_lfse_04]
	Knowledge.3 (K3)	R&D personnel and researchers, % of total employment	Eurostat [rd_p_pereg]
Social Capital (SC)	Health.1 (H1)	Life expectancy at age less than 1 year (in years)	Eurostat [demo_r_mlifexp]
	Networks.1 (N1)	% of respondents working in an organisation or association	ESS [wrkorg]
	Values.1 (V1)	Important to think of new ideas and be creative (0 – Not like me at all, 1 – Not like me, 2 – A little like me, 3 – Somewhat like me, 4 – Like me, 5 – Very much like me)	ESS [ipertiv]
Structural capital (ST)	Informational infrastructure.1 (I1)	% of enterprises with access to broadband internet	Information society in Poland GUS reports
	Transportation infrastructure.1 (T1)	Total railway lines, km per thousand square kilometres	Eurostat [tran_r_net]
	Research infrastructure.1 (R1)	Number of universities per 1,000,000 inhabitants	GUS database
	Research infrastructure.2 (R2)	Government expenditure on R&D (GOVERD), Euros per inhabitant	Eurostat [rd_e_gerdreg]
	Business infrastructure.1 (B1)	Number of centres of innovation and entrepreneurship	PARP (Bąkowski & Mażewska, 2012)

¹Data from the European Social Survey are individual level data. Before using the data to construct the composite indicators, the following steps were taken:

1. For the variable V1, the scale of answers was reversed, from 1 meaning “very much like me”, 6 meaning “not like me at all”, to 0 meaning “not like me at all” and 5 meaning “very much like me”. The goal of these operations was to turn all the variables into stimulants.
2. For the variable T1, the answers with the values 77 (“Refusal”), 88 (“Don’t know”), 99 (“No answer”) and for the variables N1 and V1, the answers with the values 7 (“Refusal”), 8 (“Don’t know”), 9 (“No answer”) have been removed. These answers were counted as invalid cases and were excluded from the calculations.
3. Data was aggregated to a regional level (NUTS-2) by calculation of the arithmetic mean of the values of all individual answers from the given regions.

Source: own elaboration

Where:

- x_{qr}^t – the value of the q -th indicator in the t -th year for the r -th region
- The minimum (*min*) and maximum (*max*) were calculated for each indicator, both across all regions r and across the whole time range T of the analysis.

The normalised indicators I_{qr}^t have values between 0 and 1. The Cronbach coefficient alpha (c-alpha) was applied as one of the methods of multivariate analysis. The c-alpha calculated for all the normalised indicators together is equal to 0.804, and it can be assumed “that the sub-indicators are measuring the same underlying construct” (Nardo et al., 2005, p. 27).

The data were aggregated as an arithmetic mean of all the normalised indicators with weight equal to one (OECD, 2008, p. 31–33):

$$IC_r^t = \frac{K1_r^t + K2_r^t + K3_r^t + H1_r^t + N1_r^t + V1_r^t + I1_r^t + T1_r^t + R1_r^t + R2_r^t + B1_r^t}{11} \quad (2)$$

Analysis was conducted for the years 2004–2014 in 16 Polish regions: Łódzkie (PL11), Mazowieckie (PL12)⁴, Małopolskie (PL21), Śląskie (PL22), Lubelskie (PL31), Podkarpackie (PL32), Świętokrzyskie (PL33), Podlaskie (PL34), Wielkopolskie (PL41), Zachodniopomorskie (PL42), Lubuskie (PL43), Dolnośląskie (PL51), Opolskie (PL52), Kujawsko-Pomorskie (PL61), Warmińsko-Mazurskie (PL62), Pomorskie (PL63).

To examine the relationship between the components of IC (human capital, social capital, structural capital) and the engagement of innovative enterprises in innovation activity (Table 2), estimation of the econometric panel models for the selected variables was performed (Table 4). The calculations were done in the R environment (R Core Team, 2021) using the *plm* package (Croissant & Millo, 2008). The panel was built for the 16 Polish NUTS-2 regions over five sets of years (2004–2006, 2006–2008, 2008–2010, 2010–2012, 2012–2014). The model (*pooled*) is based on classical OLS (ordinary least squares) regression estimated using an à la Newey and West estimator (NW) (Millo, 2017). Individual effects were tested with the Breusch-Pagan test (Breusch & Pagan, 1980). Random effects were tested with the Baltagi and Li AR-RE test (Baltagi & Li, 1991, 1995). In the case of individual effects, the fixed effect and random effect estimators should be tested (Baltagi, 2005).

The multicollinearity of the dependent variables is undesirable because it makes it impossible to estimate the model (Kufel, 2011, p. 68). For this reason, before selecting the final set of explanatory variables, the variables describing IC (Table 1) were tested for the occurrence of collinearities by determining the variance inflation

⁴ The analysis is conducted for the years 2004–2014, before the revision of the NUTS-2 classification in 2016 (COMMISSION REGULATION (EU) 2016/2066 of 21 November 2016 amending the annexes to Regulation (EC) No 1059/2003 of the European Parliament and of the Council on the establishment of a common classification of territorial units for statistics (NUTS)), and the distinction of Makroregion Województwo Mazowieckie (PL9), Warszawski stołeczny (PL91), Mazowiecki regionalny (PL92). The classification of the regions in the research is based on the previous classification.

Table 2 Indicators of innovation activity of enterprises

Innovation activity of enterprises	IRD	Percentage of innovative enterprises engaged ¹ in internal R&D activity	GUS (Community Innovation Survey) ²
	ERD	Percentage of innovative enterprises engaged in external R&D activity	
	MEA	Percentage of innovative enterprises engaged in the acquisition of machinery and equipment	
	KA	Percentage of innovative enterprises engaged in the acquisition of knowledge from external sources	

¹In 2004–2006, the CIS survey data was presented as the “percentage of enterprises which incur expenditures on various types of innovation activity”. From 2006–2008 onwards, the CIS data were presented as the “percentage of enterprises engaged in various types of innovation activity”.

²Data from the CIS were delivered by the Polish National Statistical Office (GUS) in the form of aggregated data at the NUTS-2 level

Source: own elaboration

Table 3 The value of the variance inflation factor (VIF) for the explanatory variables

	K1	K2	K3	H1	N1	V1	III	TI1	RI1	RI2	BI1
VIF	10	2	5	3	1	1	6	1	3	10	3
VIF	8	2	3	3	1	1	6	1	3	-	3

Source: own calculations in *fmsb* package in R (Nakazawa, 2018)

factor (Dudek, 2005, p. 614). The results obtained (Table 3) indicate the existence of variables that could disturb the quality of the model (for which the VIF value > 10). Although, there is a relation between a firm size and an innovation activity (Acs, Audretsch, 1987) adding of company size in the model as a control variable was impossible, because data received from GUS were already aggregated at the regional level.

The final data set used in the econometric models is presented in Table 4.

Results

In Polish regions we can observe a decrease of engagement of innovative enterprises in the acquisition of machinery and equipment between years 2004 and 2014, nevertheless it is not steady decline and fluctuations in some regions may be observed. (Figure 1, indicator MEA). In the case of other types of innovation activity, fluctuations are visible. Only in the case of the capital city region (Mazowieckie, PL12) is an increase in engagement in internal and external R&D, as well as in knowledge acquisition, observed.

In the years 2004–2014, on average, the highest level (40%) of engagement in internal R&D activity was noticed in the Mazowieckie (PL12) and Śląskie (PL22) regions, the lowest (27%) in Warmińsko-Mazurskie (PL62) (Fig. 1, indicator IRD). For external R&D, the highest engagement of enterprises was again observed in the Mazowieckie (PL12) (27% in the years 2004–2014) and Śląskie (PL22) (25% in the years 2004–2014) regions and the lowest in Warmińsko-Mazurskie (PL62) (13% in the years 2004–2014) (Fig. 1, indicator ERD). In the Lubelskie (PL31) region in the years 2004–2014, 80% of enterprises were engaged in the acquisition of machinery and equipment. The lowest level (71%) of engagement in this type of innovative activity was noticed in Łódzkie (PL11) and Mazowieckie (PL12) regions (Fig. 1, indicator MEA). For the acquisition of knowledge from external sources, the highest percentage of enterprises (22–23% in the years 2004–2014) was in the Mazowieckie (PL12) and Pomorskie (PL63) regions, the lowest (13–14% in the years 2004–2014) in the Warmińsko-Mazurskie (PL62) and Zachodniopomorskie (PL42) regions (Fig. 1, indicator KA).

The structure of the engagement of enterprises in various types of innovation activity in the Mazowieckie (PL12) region is the closest to those represented in Western European countries. The main types of innovative activity in innovative enterprises in the EU-15 countries include internal R&D and the purchase of machinery and equipment. In 2004, on average, 60% of innovative enterprises

Table 4 Description of the variables used in the models for innovation activity

Variable	Description	Data source	Years covered
Dependent variables			
ird_{it}	Innovative enterprises engaged in internal R&D activity (% of total innovative enterprises)	GUS (CIS)*	2004–2006, 2006–2008, 2008–2010, 2010–2012, 2012–2014
erd_{it}	Innovative enterprises engaged in external R&D activity (% of total innovative enterprises)		
mea_{it}	Innovative enterprises engaged in the acquisition of machinery and equipment (% of total innovative enterprises)		
ka_{it}	Innovative enterprises engaged in the acquisition of knowledge from external sources (% of total innovative enterprises)		
Independent variables (explanatory variables)			
$K1_{it}$	Tertiary education	Eurostat	2004, 2006, 2008, 2010, 2012
$K2_{it}$	Life-long learning		
$K3_{it}$	R&D personnel		
$H1_{it}$	Health		
$N1_{it}$	Social engagement with organisations		
$V1_{it}$	Value of being innovative	ESS	
$I1_{it}$	Access to the internet		
$T1_{it}$	Railway networks	PARP	
$R1_{it}$	Universities	Eurostat	
$B1_{it}$	Innovative centres	GUS	

*Data calculated by GUS based on CIS data

Notion: All the variables are expressed in natural logarithms; variable subscriptions relate to the i^{th} region in t^{th} period

Source: own elaboration

Fig. 1 Share of the various types of innovative activity in the Polish regions, % of innovative enterprises (As innovative enterprises can be engaged in more than one type of innovative activity at the same time, the values in the graphs do not add up to 100%) in the years 2004–2014. Source: own elaboration based on GUS (CIS)

conducted internal R&D activities, and in 2014 it was 52%. For comparison, in 2004 only 25% were involved in external R&D, and in 2014 this value increased to 26%. In the case of the purchase of machinery and equipment in 2004, on average, 67% of innovative enterprises were engaged in this type of innovative activity, and in 2014 it was 62%. In 2004, an average of 25% of innovative enterprises decided to purchase external knowledge, and in 2014 this value dropped to 24%. In the 10 NMS, internal R&D activity in 2004 was carried out on average by 43% of innovative enterprises, and in 2014 it was already 60%. The majority of innovative enterprises are involved in the purchase of machinery and equipment – on average 80% in 2004 and 66% in 2014. At the national level, Poland is characterised by a very high level of engagement in imitative innovation activity – in 2004, 90% of innovative enterprises were engaged in the acquisition of machinery and equipment, in 2014 it was 74%. In 2004, only 26% of innovative enterprises were engaged in internal R&D in Poland, in 2014 it was 33% (Lubacha, 2021).

The top five regions according to the IC level are the same ones across the years: Mazowieckie (PL12), Małopolskie (PL21), Śląskie (PL22), Dolnośląskie (PL51), and Pomorskie (PL63) (Table 5). The highest increase in the value of IC can be observed in the Mazowieckie (PL12) (+0.317) and Pomorskie (PL63) (+0.256) regions. In both regions, the highest increase in the percentage of the population with tertiary education (K1) (by 12 percentage points in PL12 and 10 percentage points in PL63) and an increase by 1.3 percentage points in the percentage of the population taking part in education and training (K2) can be observed. Moreover, these regions are characterised by the highest increase in GERD (RI2) – by 125 EUR per inhabitant in PL12 and 82 EUR in P63. The lowest increase in the value of IC was observed in Zachodniopomorskie (PL42) (+0.095) and Podlaskie (PL34) (+0.118). In both regions, the percentage of the population taking part in education and training decreased and both regions were characterised by a very low increase in governmental R&D expenditure (by 20 EUR per inhabitant in PL42 and 19 EUR in PL34).

The Świętokrzyskie (PL33) and Lubuskie (PL43) regions are characterised by the lowest level of the value of IC in most of the analysed years, and is ranked in the lowest position (with the exception of 2008 for Świętokrzyskie (PL33)). In 2004, the Świętokrzyskie (PL33) region was characterised by the lowest level of three of the nine indicators, and average or below average levels for the remaining indicators. In the Świętokrzyskie (PL33) region in 2004, R&D personnel and researchers consisted of 0.23% of total employment (K3) and GERD was at the level of 3.1 EUR per inhabitant (RI2). In Lubuskie (PL43) all indicators were below average levels in 2004. In 2012, R&D personnel and researchers decreased to 0.14% in Świętokrzyskie (PL33) and to 0.28% in Lubuskie (PL43). The level



Table 5 Ranking of Polish regions according to the value of the regional IC index

Year Region	2004		2006		2008		2010		2012	
	value	rank	value	rank	value	rank	value	rank	value	rank
PL11 Łódzkie	0.241	10	0.235	13	0.256	14	0.347	12	0.391	11
PL12 Mazowieckie	0.468	1	0.545	1	0.632	1	0.729	1	0.785	1
PL21 Małopolskie	0.358	2	0.369	4	0.444	4	0.506	5	0.598	2
PL22 Śląskie	0.350	3	0.393	2	0.446	3	0.532	3	0.558	3
PL31 Lubelskie	0.269	9	0.266	9	0.327	7	0.422	7	0.465	7
PL32 Podkarpackie	0.223	11	0.251	11	0.283	12	0.324	14	0.421	8
PL33 Świętokrzyskie	0.168	15	0.179	15	0.289	11	0.293	16	0.337	14
PL34 Podlaskie	0.277	7	0.287	8	0.322	9	0.394	9	0.396	10
PL41 Wielkopolskie	0.277	8	0.350	6	0.378	6	0.470	6	0.485	6
PL42 Zachodniopomorskie	0.317	5	0.298	7	0.323	8	0.417	8	0.412	9
PL43 Lubuskie	0.167	16	0.190	14	0.190	16	0.332	13	0.305	16
PL51 Dolnośląskie	0.320	4	0.388	3	0.447	2	0.532	2	0.553	4
PL52 Opolskie	0.210	13	0.251	11	0.307	10	0.352	11	0.333	15
PL61 Kujawsko-Pomorskie	0.213	12	0.240	12	0.258	13	0.317	15	0.389	12
PL62 Warmińsko-Mazurskie	0.172	14	0.153	16	0.232	15	0.377	10	0.359	13
PL63 Pomorskie	0.281	6	0.367	5	0.397	5	0.513	4	0.536	5

Source: own calculations

of the remaining indicators increased, but they are still at a level far below the average for the Polish regions (Fig. 2).

For the human capital indicators (Fig. 2), we can see an increase in the percentage of the population with tertiary education (K1) in all regions – from 15% on average in 2004 to 23% in 2012. The percentage of the population taking part in education and training (K2) and R&D personnel and researchers (K3) decreased in most Polish regions. K2 increased only in Mazowieckie (PL12) and Pomorskie (PL63) by 1.2 and 1.3 percentage points, respectively. K3 increased significantly (by 0.46 percentage points) in Podkarpackie (PL32). In all regions, life expectancy increased by 1–2 years. It was the lowest in Łódzkie (PL11) in 2004 (73.8 years) and 2012 (75.2

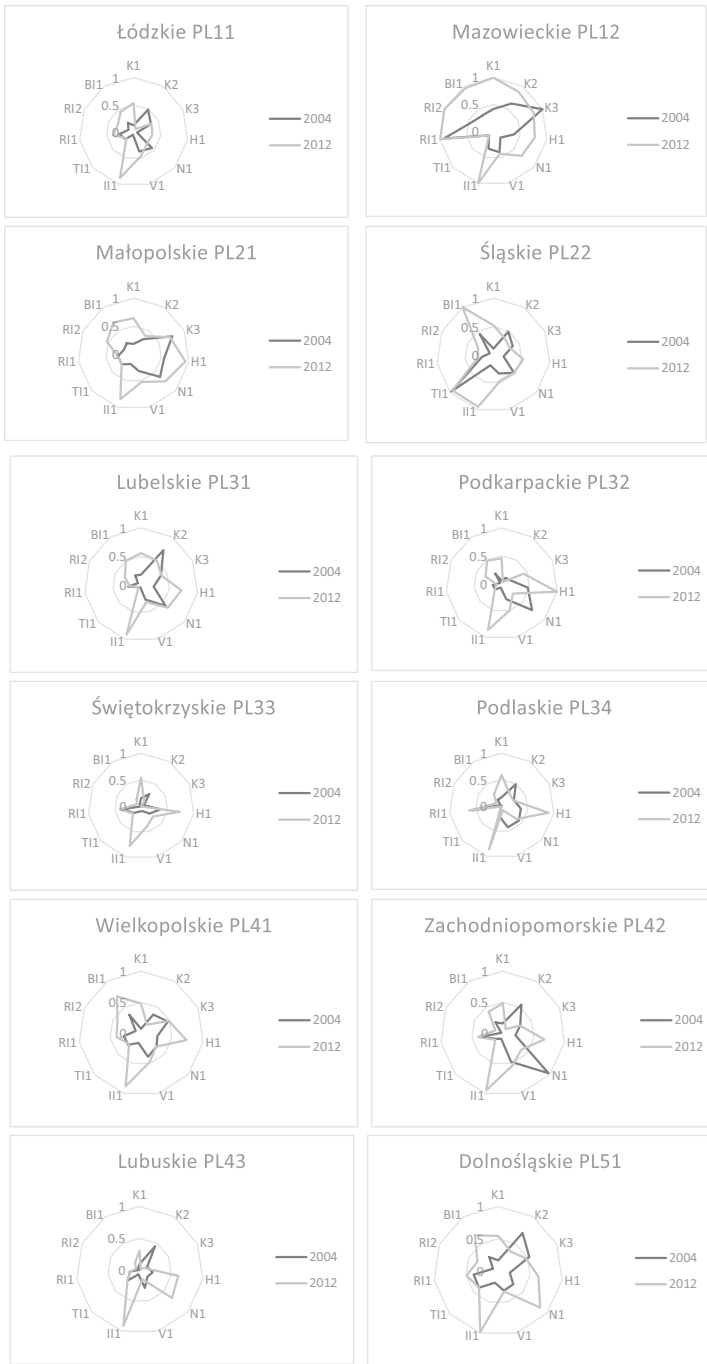


Fig. 2 Normalised value of the individual indicators of IC in the Polish regions in the years 2004 and 2012. Source: own elaboration

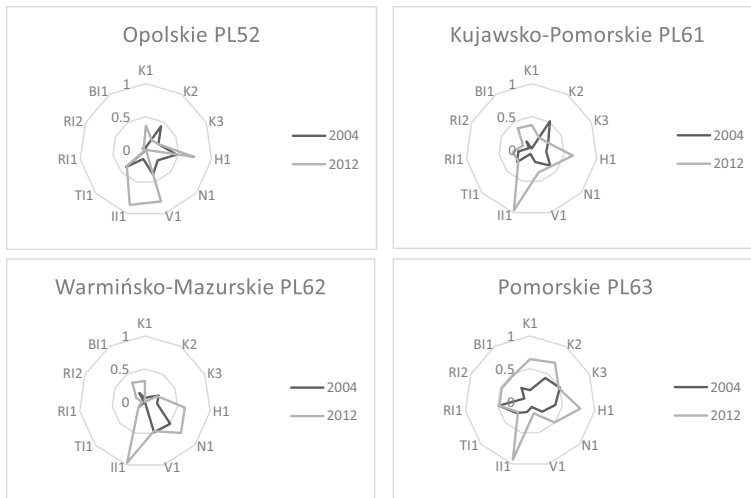


Fig. 2 (continued)

years). Most indicators of social capital (Fig. 2) increased in the analysed period, with only N1 decreasing in half of the regions. In all regions, respondents value creative thinking (V1) at a similar level, equal to 3 (Somewhat like me). Only in Opolskie (PL52) in 2012 did respondents value creative thinking more (indicator equal to 4 – “Like me”). The most significant increase (200–300% on average) in structural capital (Fig. 2) indicators can be seen in the percentage of enterprises with access to the broadband internet (II1) (from 35% in 2004 to 81% in 2012) and GERD (RI2) (from 21 EUR per inhabitant in 2004 to 64 EUR in 2012). The highest increase in access to the broadband internet was observed in Warmińsko-Mazurskie (PL62) (by 56 percentage points), the lowest in Małopolskie (PL21) (by 38 percentage points). In Mazowieckie (PL12) we observed the highest increase in GERD (by 125 EUR per inhabitant), in Opolskie (PL52) – the lowest increase by 10 EUR. Total railway lines (TI1) decreased by about 4 km per 1000 km² in half of the regions; in six regions these increased by 1–4 km per 1000 km². The number of universities per 1,000,000 inhabitants (RI1) is stable in most regions – in half of the regions this stayed unchanged, in rest it increased by 1–2 universities.

In the case of both models for innovation activity, the results of the Breusch-Pagan test ($p > 0.05$) do not allow rejection of the hypothesis about a lack of individual effects. Likewise, the results of the Baltagi and Li AR-RE test ($p > 0.05$) do not allow rejection of the hypothesis about a lack of random effects. Therefore, the results of the OLS models can be interpreted as reliable (Table 6).

In the model for internal R&D activity (ird_{it}), human capital, social capital and structural capital in the regions were found to be significant. In the model for external R&D activity (erd_{it}), human capital and structural capital in the regions were found to be significant. Hypothesis 1 can be partially confirmed, as the higher percentage of people with tertiary education (K1) and higher percentage of R&D personnel (K3) were found to be positively related to internal and external R&D

Table 6 Determinants of the various types of innovation activity (pooling, NW)

Model	ird_{it}	erd_{it}	mea_{it}	ka_{it}
<i>intercept</i>	6.5491 (0.3280)	-2.4560 (0.8028)	-0.8140 (0.8170)	-15.6511 (0.2347)
$K1_{it}$	0.6411 (0.0004)***	0.6985 (0.0037)**	-0.3080 (0.0043)**	-0.1792 (0.6228)
$K2_{it}$	-0.2485 (0.0091)**	-0.1084 (0.5207)	0.1713 (0.0020)**	0.1362 (0.4076)
$K3_{it}$	0.1120 (0.0077)**	0.1349 (0.0381)*	-0.0142 (0.5733)	-0.0740 (0.4180)
$H1_{it}$	-0.8912 (0.5697)	1.0612 (0.6429)	1.4110 (0.0965)	4.0327 (0.1945)
$N1_{it}$	0.0451 (0.2338)	0.0347 (0.3127)	-0.0051 (0.7580)	-0.1234 (0.0837)
$V1_{it}$	-0.0027 (0.9912)	-0.6524 (0.0797)	-0.2206 (0.1583)	-0.8882 (0.1047)
$II1_{it}$	-0.4246 (0.0004)***	-0.4338 (0.0066)**	-0.0457 (0.4045)	0.1336 (0.4921)
$TI1_{it}$	0.2617 (0.0000)***	0.3094 (0.0031)**	-0.0137 (0.6930)	0.1193 (0.3562)
$RI1_{it}$	0.1551 (0.0652)	0.1177 (0.4779)	-0.0024 (0.9661)	0.2093 (0.2625)
$BI1_{it}$	-0.1223 (0.0158)*	-0.0267 (0.7646)	0.0496 (0.0809)	0.2795 (0.0147)*
Model's parameters	Balanced panel: n = 16, T = 5, N = 80			
<i>R-Squared</i>	0.39463	0.38476	0.40034	0.29695
<i>Adj. R-Squared</i>	0.30689	0.2956	0.31343	0.19506
<i>F-statistic</i>	7.00882 on 10 and 4 DF, p-value: 0.0378	9.08525 on 10 and 4 DF, p-value: 0.023815	8.17141 on 10 and 4 DF, p-value: 0.02881	F-statistic: 2.83151 on 10 and 4 DF, p-value: 0.16385
<i>Breusch-Pagan test (individual effects)</i>	$\chi^2 = 0.1974$, df = 1, p-value = 0.6568	$\chi^2 = 2.8093$, df = 1, p-value = 0.09372	$\chi^2 = 0.01713$, df = 1, p-value = 0.8959	$\chi^2 = 0.18194$, df = 1, p-value = 0.6697
<i>Baltagi and Li AR-RE joint test</i>	$\chi^2 = 5.3136$, df = 2, p-value = 0.07017	$\chi^2 = 3.2735$, df = 2, p-value = 0.1946	$\chi^2 = 1.2748$, df = 2, p-value = 0.5287	$\chi^2 = 1.2671$, df = 2, p-value = 0.5307

Source: own calculations with *plm* package in R (Croissant & Millo, 2008).

Signif. codes: * 0.05, ** 0.01; *** 0.001

activity. These findings are in line with previous research, according to which human capital is positively related with innovations measured as R&D activity (e.g., Dakhli & de Clercq, 2004; Kiuru & Inkinen, 2017). Nevertheless, higher level of life-long learning (K2) was negatively related to internal R&D activity. In the model for the acquisition of machinery and equipment (mea_{it}), human capital was found to be significant. Hypothesis 2 can be partially confirmed – a higher percentage of people with tertiary education (K1) was found to be negatively related to engagement in the acquisition of machinery and equipment. Although, a higher level of life-long learning (K2) was positively related with the acquisition of machinery and equipment. Imitative innovation (the introduction of new machinery and equipment) demands an adjustment in the level of knowledge about new production processes. Therefore, additional training is required for the application of new machinery and equipment in a company (Dyker, 2006; Leonard-Barton & Kraus, 1985, Odei et al. 2021).

Hypothesis 3 cannot be confirmed because the level of social capital indicators (N1, V1) was found to be insignificant for both types of R&D activity. Hypothesis 4 cannot be confirmed as the level of social capital indicators (N1, V1) was found to be insignificant for engagement in the acquisition of machinery and equipment.

Hypothesis 5 may be partially confirmed. The number of railway lines (TI1) is positively related to internal and external R&D activity. For the acquisition of machinery and software it was insignificant. New research shows that high-speed railway connections increase innovation in regions (Yang et al., 2021). Higher railway density allows smaller cities to connect with the central city in a region (Wang & Cai, 2020). It was also the case of Polish regions in the analysed period. According to Smolarski (2021) in years 2006–2015 14 passenger traffic railway lines were suspended and in the same time 39 lines were reactivated. In most cases they were lines connecting smaller cities with the central city in a region. This process was related to the regionalization and self-governance of rail transport in Poland. Moreover, from 2010 chosen passenger lines have been modernised and transformed into high-speed railways (Koziarski, 2017). The share of enterprises with access to the broadband internet (II1) was found to be negatively related to internal and external R&D activity, which contradicts previous findings (e.g., Xu et al., 2019). According to the Information society in Poland GUS reports (Gontarczuk et al., 2008; Berezowska et al. 2012) in 2004 in 33% of companies employees used computers in work (in 21% of companies computers with access to internet) and this value increased just to 42% (36% with access to internet) in 2012. In the same time access to the broadband internet had over 70–80% of companies. It may be considered as an explanation for these contradictory results – despite the access to the broadband internet companies did not use it in the everyday operation in the analysed period. Other possible explanation can be related to changes in the methodology of the innovation survey. In 2004–2006, the CIS data was presented as the “percentage of enterprises which incur expenditures on various types of innovation activity”; from 2006–2008 onwards, the CIS data was presented as the “percentage of enterprises engaged in various types of innovation activity”. For the data presented in Fig. 1, it can

be seen in 2004–2006 that enterprises in most regions reported a higher level of engagement in internal R&D than in 2006–2008 when the question was changed. This can be accounted for by the imperfections of the survey data, and difficulties with distinguishing what can be reported as internal R&D and what cannot. The previous question on expenditure was more straightforward and easier for companies to answer. When the data for 2004–2006 are included, a very high level of internal R&D is visible accompanied by a very low level of III (Fig. 3).

However, number of centres of innovation and entrepreneurship (BI1) was found to be negatively related to internal R&D. Data collected at the regional level includes all types of business infrastructure: technology parks, technology transfer centres, technology incubators, academic business incubators, seed funds and business angel networks (considered as innovation support infrastructure) and local and regional loan funds and training and advisory centres (considered as entrepreneurship support infrastructure). While analysing national level data it can be noticed that in 2004 only 20% of centres were innovation centres and in 2012 it was already 44%. Although, increase in numbers of seed capital funds, technology parks and incubators was observed in 2012 and many of them started operating since 2012, therefore the expected positive impact of them cannot be reflected in analysed period (Bąkowski & Mażewska, 2012).

GERD (RI2) were excluded from the model because of the high collinearity with human capital indicators (Fig. 4).

In the case of knowledge acquisition (ka_{it}), the estimation results are inconclusive, as the p -value is higher than 0.10 (Ramsey & Schafer, 2002).

Fig. 3 Scatter plot for internal R&D (IRD) and access to the internet (III). Source: own calculations with *Graphics* package in R (R Core Team, 2021)

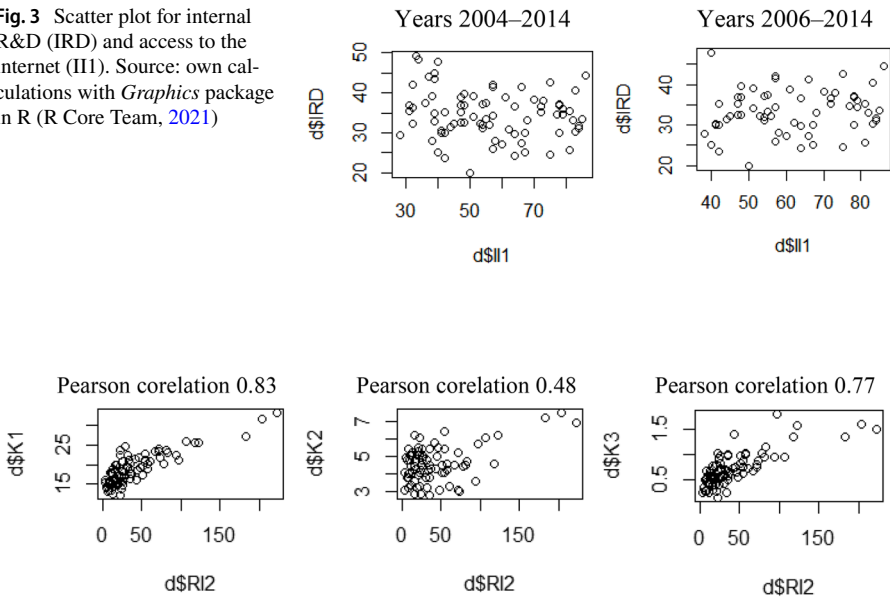


Fig. 4 Scatter plot for GERD (IR2) and human capital indicators (K1, K2, K3). Source: own calculations with *Stats* and *Graphics* package in R (R Core Team, 2021)

Conclusions

Intangible assets such as IC play an important role in the innovation activity of enterprises operating in a region. Various types of innovation activity were analysed. The Polish regions are characterised by domination of the acquisition of machinery and equipment. Engagement in this type of activity fluctuated in the analysed period. Engagement in internal and external R&D varies between regions. The capital city region (Mazowieckie (PL12)) was characterised by a mix of innovation activity similar to that in Western European countries – engagement in R&D activities and the acquisition of machinery and equipment are at similar levels.

Human capital was found to be positively related with the level of internal and external R&D activity, which is in line with previous research (e.g., Dakhli & Clercq, 2004; Kiuru & Inkinen, 2017). In the case of machinery and equipment acquisition, a higher percentage of the population with tertiary education was negatively related. A higher percentage of the population taking part in education and training was positively related to the acquisition of machinery and equipment, as the introduction of new production processes required additional training and new skills for employees (Dyker, 2006; Leonard-Barton & Kraus, 1985).

Structural capital was found to be positively related to internal and external R&D activity. A denser railway network increases innovativeness in regions and allows smaller towns to connect with main city in a region (Yang et al., 2021; Wang & Cai, 2020). However, the level of access to the internet was found to be negatively related to internal R&D activity which contradicts previous research (Xu et al., 2019). This may be caused by changes to the CIS questionnaire between the 2004–2006 wave and that of 2006–2008.

The use of survey data may be considered as a limitation of the study. The CIS is based on a standardised questionnaire used among EU countries, nevertheless, the questions may change between waves. This can cause breaks in the datasets or affect the way companies answer the questions. The ESS is also based on a standardised questionnaire, and in the case of the question about norms and values we may get results which express the attitude towards norms, not how the norms are expressed in reality. One more limitation of the use of CIS and ESS data is the limited number of observations; both surveys are taken every second year, so in the analysis of the years 2004–2014 only five points in time are available not ten, which decreases the number of observations for the panel models.

As the CIS is undertaken in most EU countries it is possible to extend the analysis to more EU regions, and further research in this direction would allow comparison of the importance of regional intangible assets for innovation activity or if the innovative environment at a national level is more important. Moreover, the determinants of knowledge acquisition have to be analysed further because in the analysis presented here, the model for knowledge acquisition is inconclusive.

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