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Completed Research Paper

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Abstract

Knowledge-intensive industries has become a major source of competitive advantage and innovation. However, there is no general agreement about the innovation pathways of knowledge-intensive enterprises. A possible explanation for this might be that the complex pathways has thus far been studied using regression models that capture only the main regression effects. To address this issue, we use fuzzy set qualitative comparative analysis that examines relationships (even asymmetrical) between the enterprises' innovation activity and all possible configurations of its determinants, including obstacles, knowledge sources, collaborative activities and R&D. We investigate this framework in the case study of German knowledge-intensive enterprises. The results show that several pathways act as sufficient conditions for product innovation. However, the effects of these conditions are asymmetric. In addition, the following complementary relationships between the determinants were observed: (1) public support and education knowledge source; (2) internal and external R&D and collaboration on innovation; and (3) internal and market knowledge source and publicly available knowledge acquired from other sources such as conferences, journals and professional associations. Thus, these findings may provide an explanation of the inconsistent effects observed in previous studies on product innovation.

Keywords: Innovation path, product innovation, fuzzy set, qualitative analysis

Introduction

Many studies have confirmed that the quality of the economic environment, institutional factors and knowledge use are the conditions for rapid technological changes and the successful creation of innovations (Acs and Audretsch, 1988; Shafik, 1994; Lee, 2001; Rennings et al., 2006). According to Wintjes and Hollanders (2011) a region's position and attitude towards technology is determined by three features: the accessibility of the region; how technology can be absorbed by the region and how knowledge diffuses regionally. This environment configuration significantly determines the innovative activity of enterprises (Massard et al. 2009). There are many ways to use the determinants and how to influence them by public policies and private interventions.

The regional accessibility is one of the key determinants which is related to connectivity, i.e. with the enterprises' ability to be involved (and participate) in regional knowledge-based or cooperation-based networks (Ponds, 2010). The aim of such networks is to find easy and fast a partner for cooperation and realize R&D and innovation activities in the knowledge network (Owen-Smith, 2004; Prokop et al., 2017). It is obvious that cooperation will be easier to run if the region will have enough infrastructure elements focusing on research activities, knowledge transfer and cooperation (typically in the form of industrial science and research parks, scientific centers, incubators and start-ups, Stejskal et al. (2016); realized for example in Silicon Valley, for more see Saxenian, 1990). Government can support and implement these elements as public investments, and promote the regional actors and their accessibility in the markets (Asheim et al., 2005; Fitjar et al., 2013).

The capacity of the knowledge-based entrepreneurs is the second major determinant. Their absorption capacity is the ability to absorb knowledge (external, Minbaeva et al., 2014) or create knowledge (internal, Berchicci, 2013). The capacity is determined by the employees in the firms, as well as the knowledge partners and their ability to exploit knowledge stock, to generate and acquire new knowledge (Song, 2014). Scholars have shown that the knowledge use significantly affects the speed, cost and quality of produced innovations. Some firms are trying to influence their absorption capability by purchasing knowledge in the market (or whole innovation), as well as by in-house research (Arora et al., 2014). However, all processes are significantly affected by the willingness of private investors to invest into the capacity increasing and creating innovations, as well as by the degree of openness and willingness to share knowledge. Here we must highlight the paradox of openness (the creation of innovations often requires openness, but the commercialization of innovations requires protection; Laursen and Salter, 2014). They proved that this relationship is less pronounced for both external search and formal collaboration if firms do not draw ideas from or collaborate with competitors. Arora et al. (2016) stated that leading firms are more vulnerable to unintended knowledge spillovers during collaboration as compared to followers, and consequently, the increase in patenting due to openness is higher for leaders than for followers.

Firms can also outsource the research activities or at least a substantial part of knowledge intensive processes due to lack of knowledge (and private financial sources for in-house research) (Qian et al., 2016). Wei (2016) points to a possible bilateral moral hazard as the weakness of the outsourcing. The knowledge spillover effects are generated from all described forms of research activities (Teirlinck and Spithoven, 2013). These are unintended positive effect that strengthens the absorptive capacity of both - the knowledge recipient and also the provider (Paci et al., 2014). The absorption capacity is also influenced with new technologies which increase the need for highly skilled workers for the efficient use.

The diffusion of the knowledge and the technologies is a third group of conditions in innovation environment (Bahar et al, 2014). Its importance is high for technical or knowledge-intensive production (typically in high-tech production or high quality production for the demanding customers on international markets; Liu et al., 2014). Also here we must emphasize the importance of the ties between the creation of knowledge-intensive products and quality of the research (internal or external). Both significantly affect the whole knowledge diffusion processes. Thanks to the high quality of products, the firms can enter the international market. This requires the high skilled workers, also their mobility and ability to use the internal and external spillover effects (Poole, 2013).

The presented conceptual framework "accessibility-absorption-diffusion" has to be seen perceived in three levels: micro (individual workers and firms), mezzo (regional policy dimension, regional government and public and R&D institutions) and macro (sectoral, national or international support of knowledge transfers, public investments to the R&D) (Massard and Mehier, 2009). It should be noted that there are many obstacles to the use of the described concept. Even high firm and employee potential may be limited by the capabilities to transmit or sell (diffuse) knowledge or by access to new knowledge in the market (Wintjes and Hollanders, 2011). The revealing of the low capacities of the firms or industries may help improve the economic performance not only of the firm but also of the region.

Initial public (European cohesion) policy was focused just on the detection of low capacity in the regions and on high public investments. The infrastructure buildings (to increase the accessibility) and the support of absorption in structurally affected regions were the aims of this regional policy (McCann and Ortega-Argiles, 2015). However, the reformed view admits that there is a high diversity and specifics in the regions. This new approach seeks for the specific regions with untapped potential and to propose the individual specific solutions how to solve the obstacles (Camagni and Capello, 2013). This leads to rational public interventions that promote the regional knowledge-based economy with multidimensional aspects (Audretsch et al., 2016; Stejskal and Hajek, 2016).

This approach includes the support for variety of knowledge-based activities and regional actors (typically those that collaborate on triple helix principle). The regions use their own approaches, prepare own strategies and apply their own regional policy. According to Wintjes and Hollanders (2011) other aspects of knowledge economies, such as education, ICT-usage, life-long learning and high- and medium-high tech manufacturing are more important for absorbing and applying technologies developed elsewhere and therefore could play an important role in processes of convergence and catching up at regional level. Therefore, many regions in developed countries use regional innovation systems and innovation strategies (innovation-oriented policy; Cooke, 1996; Chung, 2002; Hajek et al., 2014; Lau and Lo, 2015) and focus on the knowledge intensive industries mostly.

In practice of knowledge intensive industries, the combination of excellence-based and place-based policies must be applied. It helps remove the obstacles of innovation activities in finances, knowledge and market (Martin and Salomon, 2005). Simultaneously, it supports the use the smart specialisation or open innovation concepts (Feller, 2009). It affects the economic performance of firms, industries and also the economy; the volume of knowledge spillover effects (Bouncken and Kraus, 2013). The increased mobility of scientists and talented students among the high-tech firms can be the specific external effect.

Therefore, the aim of this paper is to identify combinations of determinants (positive - incentives and their inadequacy - obstacles) and modelling their effects on innovation activities in German knowledge intensive industries (Broekel et al., 2015). The paper analyzes the innovation paths base on fuzzy set qualitative comparative analysis (fsQCA). German knowledge intensive firms were chosen because Germany is the world's major economy; Germany is the global leader on whose economy other developed countries depend. For German companies, there is a presumption that discovered and described effects are also transferable to the practice of other countries (Robin, et al., 2013; Hajek and Stejskal, 2016).

The paper is structured as follows. The next section presents our research methodology, including theoretical background on fsQCA as a tool for modelling of both the complex decision-making process of survey respondents and asymmetrical relationships. Further, we present empirical research on innovation paths in German knowledge-intensive firms. The paper ends with conclusions that encompass aspects of scientific debate on the results of the research presented here as well as their implications.

Research Methodology

To model the innovation paths of knowledge intensive enterprises, we employed fsQCA. This method represents an extension of binary QCA by adding uncertainty degree to the given set (Woodside, 2013; Woodside, 2014). The advantages of the fsQCA over traditional regression methods have been demonstrated, for example, on the model of configurational paths to organizational innovation (Ganter and Hecker, 2014). The fsQCA enables modelling of both the complex decision-making process of survey respondents and asymmetrical relationships (i.e. not only the main regression effects) in the data (Woodside, 2014). The method empirically examines the relationships between all possible combinations of predictors and the predicted output. In other words, it uses fuzzy sets to identify necessary and sufficient conditions for the output. To perform the fsQCA, property space should be defined and fuzzy set memberships should be assigned first (Ordanini et al., 2014). Next, consistency in set relations is evaluated and logical reduction is carried out.

Background theoretical knowledge is used to define the property space. In this step, all possible input configurations (innovation determinants in this study) for the output variable (innovation activity) have to proposed, see Fig. 1. The innovation determinants include factors hampering product and process innovation activities such as lacks of funds, qualified personnel or market demand (Savignac, 2008). Another important determinant is organisational competence such as internal/external knowledge acquisition, internal/external R&D and collaboration (Cassiman and Veugelers, 2006; Berchicci, 2013; and many others). Finally, the use of national/European public resources to support R&D have to be taken into account (Franco and Gussoni, 2014). To validate the effects of the above-mentioned determinants on innovation activity (theoretical framework in Fig. 1), we used fsQCA. We hypothesize that these effects will appear in the resulting innovation paths obtained by the fsQCA and that these paths will provide highly consistent and representative results. This style of validation corresponds to qualitative comparative analyses presented in previous studies on organizational innovation paths (Ganter and Hecker, 2014).

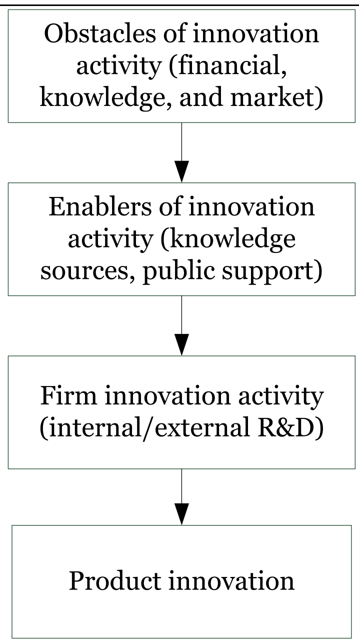

Figure 1. Theoretical Framework for Innovation Paths

The fuzzy set memberships of the binary determinants were simply 0 or 1. For continuous variables, the memberships were determined as the sum of the degrees divided by the maximum score possible. Each source of knowledge acquisition (and the obstacles of innovation activity) was measured on a 0-3 scale. For example, knowledge acquisition from market sources included four sources, namely suppliers, clients, competitors and consultants. Thus, the fuzzy set membership was calculated as the sum of the degrees divided by 12. Similarly, the fuzzy set membership was 1 for the enterprises participating in the EU 7th Framework Programme for Research and Technical Development, 0.75 for EU funding, 0.5 for central government funding, 0.25 for local or regional funding, and 0 for no external financial support. Finally, the degree of collaboration was 1 for enterprises collaborating with other enterprises within enterprise group, market, and educational partners at the same time, 0.67 for two collaborative partners, 0.33 for one of them, and 0 for no collaboration.

In the next step of the fsQCA, the variables were combined in various configurations (paths). For each path, we also calculated fuzzy set memberships using Gödel's *t*-norm MIN. The quality of the paths was measured using consistency (the proportion of condition covered by the outcome). Logical reduction is carried out to discard redundant paths. The coverage of the resulting paths can be calculated as the share of consistent fuzzy set memberships in the sum of all the fuzzy set memberships in the output.

Data

The data for the fsQCA were obtained from the German Community Innovation Survey (CIS). The survey used a harmonized questionnaire and it was carried out by the Eurostat for the period 2010-2012 by combining stratified random sampling and exhaustive surveys of enterprises with at least 10 employees. From the 6,328 German enterprises in the dataset, we focused only on those in knowledge-intensive industries (2,183 enterprises). Specifically, our analysis was limited to the industries for which tertiary educated persons employed represent more than 33% of the total employment (Eurostat definition). As reported in the growing body of related literature (Domenech et al., 2016), the knowledge-intensive industries have become a fundamental source of innovation, thus driving economic growth and regional development.

The basic statistical characteristics of the dataset are given in Table 1 (continuous variables) and Table 2 (categorical variables). The tables show that the average turnover in the year 2012 (market sales of goods and services) was about 441 mil. Euro and most of the enterprises were small (with less than 50 employees). Further, the majority of enterprises introduced goods or service innovations (new or significantly improved goods or services), and about 12% of the turnover was from new or significantly improved products (new to market or new to firm). Regarding R&D activities, half of the enterprises undertaken them in-house, while less than quarter of the enterprises contracted out R&D to other enterprises or public/private research organizations. In order to innovate goods or services, about half of the enterprises acquired advanced machinery, equipment, software and buildings. A quarter of the enterprises acquired existing know-how, copyright, or patented (non-patented) inventions from other organizations. Interestingly, most of the enterprises did not receive any public financial support (local/regional/central government/the EU) for innovation activities. About a third of the enterprises collaborated on their innovation activities with other enterprises or institutions (suppliers, clients, competitors, consultants, universities, or public/private research institutes).

Variable	Mean±St.Dev.
Turnover in 2012 (thousand Euro)	440,864±2,107,884
Percentage of total turnover from new products [%]	12.17±21.30
Internal knowledge source (within enterprise)	1.79±1.32
Market knowledge source (suppliers, clients, competitors)	1.77±1.26
Education and research institutes knowledge source	0.92±1.08
Other knowl. sources (conferences, journals, professional associations)	1.33±1.13
Financial obstacles of innovation (lack of finance, high cost of access to new markets)	1.75±1.05
Knowledge obstacles of innovation (lack of qualified personnel)	1.56±0.98
Market obstacles of innovation (price competition, lack of demand, innovations by competitors)	2.53±0.75
Number of enterprises *N*	2,183

Table 1. Average Values (± Standard Deviation) of Continuous Variables for German Knowledge Intensive Enterprises

We also included the knowledge sources for innovation, with four categories (internal, market, education and research institutes, and other) indicating their importance (from 0 – not important to 3 – highly important) to enterprise's innovation activities. Internal and market knowledge sources were the most important categories. Finally, the enterprises identified the importance of obstacles to innovation activities. We categorized them into financial, knowledge, and market obstacles. As presented in Table 1, the market obstacles of innovation such as competition and the lack of demand were the most critical.

Results

Table 3 shows the results of the fsQCA, depicting nine paths to achieve product/process innovation. The visualization is based on related studies (Bell et al., 2014; Fiss, 2011, Misangyi and Acharya, 2014). Path P1 states that market obstacles are tackled by utilizing both internal and external knowledge sources, and internal R&D supplied with the acquisition of machinery, equipment, software & buildings. Path P2 is similar, but these enterprises suffer from the lack of qualified personnel and, thus, no R&D can be performed. Path P3 differs from Path 1 only in terms of financial obstacles. Path P4 is similar to Path P2. However, in contrast to knowledge obstacles, it is the financial obstacles that hamper internal R&D. Enterprises following path P5 rely purely on qualified personnel, without any R&D activities or knowledge acquisition. Path P6 offers a different solution based on the acquisition of machinery. Path P7 is based on internal and external knowledge sources only, resulting from the concurrent existence of financial, knowledge and market obstacles. Similar issues are addressed in path P8 with internal R&D and the acquisition of machinery. Path P9 provides the most complex configuration, utilizing public support and all types of knowledge sources on one hand, and collaborative internal and external R&D with the acquisition of machinery and existing knowledge on the other hand.

Variable	Category	Frequency
Number of employees	under 50	52.8%
	50-249	21.7%
	250-499	6.0%
	500 and more	19.5%
Innovative	yes	56.4%
	no	43.6%
In-house R&D	yes	50.0%
	no	50.0%
External R&D	yes	23.4%
	no	76.6%
Acquisition of machinery, equipment, software & buildings	yes	49.5%
	no	50.5%
Acquisition of existing knowledge	yes	24.1%
	no	75.9%
Public financial support	yes	27.9%
	no	72.1%
Collaboration on innovation activities	yes	33.8%
	no	66.2%
Number of enterprises *N*		2,183

Table 2. Relative Frequencies of Categorical Variables for German Knowledge Intensive Enterprises

Table 3 shows that the resulting paths had sufficient consistency (> 0.55), although consistency scores for P6 and P7 are lower than the recommended reference score 0.75 (Ragin, 2006; 2008). This is mainly due to the presence of the negation of in-house R&D (rrdin). For most firms, in-house R&D is the primary prerequisite for their innovation activity. This suggests that P6 and P7 represent the configuration paths taken by small and medium-sized firms. Overall, the solution of the fsQCA achieved the consistency measure of 0.7738. Furthermore, the coverage of the solution was 0.2158. Regarding individual paths, P9 was the most consistent one, while path P4 had the largest coverage. On the other hand, path P9 uniquely covered the largest proportion of fuzzy set memberships.

To further examine each path, we compared the frequencies of innovative enterprises in terms of innovative activity outcome (measured as the proportion of total turnover from new products - TURNIN). Wu et al. (2014) categorized the relationships between input variables and outcome as follows: (1) rectangular, (2) symmetrical, (3) asymmetric – sufficient but not necessary, and (4) asymmetric – insufficient but necessary. In the asymmetric relationships, positive (a low input leads to a high outcome) and negative contrarian cases (a high input leads to a low outcome) are present. The results presented in Fig. 2 suggest the existence of positive contrarian cases in the innovation activity. This indicates that the detected paths are sufficient but not necessary configurations for the innovation activity in German knowledge intensive industries. In fact, the overall coverage of the solution also suggests that the 9 paths identified by the fsQCA explained only a relatively low percentage of innovation behaviour. Specifically, Table 4 presents the membership degrees of any of the nine paths obtained by applying Gödel's *t*-conorm MAX. The results suggest that enterprises following any of the identified paths are more innovative than their counterparts (except the membership degree of 0.75). They also show that the nine paths represent about a half of the innovative enterprises.

Categ.	Var.	P1	P2	P3	P4	P5	P6	P7	P8	P9
Obstacles	obsmar	+	+	+	+	+	+	+	+	+
	obsknow		+		+	~		+	+	
	obsfin			+	+	+	+	+	+	+
Enablers	funpub	~	~	~	~	~	~	~	~	+
	sentg	+	+	+	+	+	+	+	+	+
	smar	+	+	+	+	+	+	+	+	+
	sedu	~	~	~	~	~	~	~		+
	soth	+	+	+	+	~	~	+	+	+
Firm activity	rrdin	+		+			~	~	+	+
	rrdex	~	~	~	~	~	~	~	~	+
	rmac	+	+	+	+	~	+		+	+
	roek	~	~			~	~	~	~	+
	co	~	~	~	~	~	~	~	~	+
Raw coverage		0.0674	0.0735	0.0767	0.0925	0.0281	0.0191	0.0329	0.0584	0.0406
Unique coverage		0.0034	0.0041	0.0030	0.0134	0.0194	0.0083	0.0096	0.0103	0.0406
Consistency		0.8512	0.7436	0.8596	0.7558	0.7583	0.5562	0.5769	0.8623	0.9131
Overall coverage		**0.2158**								
Overall consistency		**0.7738**								

Table 3. Paths of Innovation Activity in German Knowledge Intensive Industries

Legend: ~ denotes logical negation, obsfin – financial obstacles, obsknow – knowledge obstacles, obsmar – market obstacles, funpub – public funding, sentg – internal knowledge sources, smar – market knowledge sources, sedu – educational knowledge sources, soth – other knowledge sources, rrdin – internal R&D, rrdex – external R&D, rmac – acquisition of machinery, roek – acquisition of existing knowledge, and co – collaboration on innovative activities.

Membership degree of paths P1-P9	Non-innovative [%]	Innovative [%]
0.00	35.3	29.8
0.25	0.1	0.5
0.33	5.7	15.4
0.50	0.3	1.7
0.67	2.1	8.7
0.75	0.1	0.0
1.00	0.0	0.3
Total	43.6	56.4

Table 4. Membership Degrees of fsQCA Paths vs. Product Innovativeness

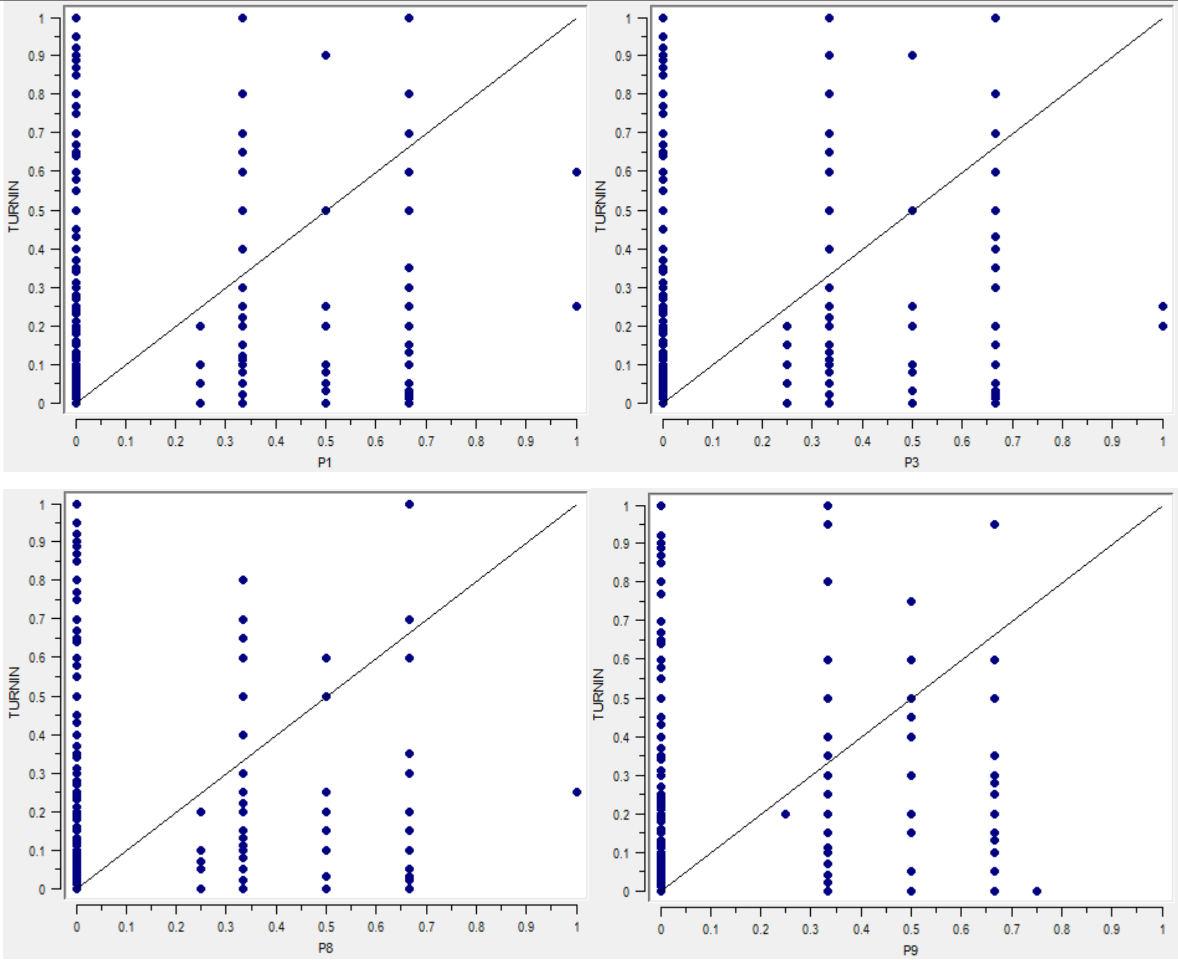

Figure 2. Relationships between Innovation Paths with Highest Consistency and Innovation Activity

Conclusion

It was proven that entrepreneurs and various cooperation forms must face various obstacles. These make their business activities more difficult and complicate a competitive advantage gaining in global markets. Many obstacles (in finance, market and knowledge categories) have been described in this paper. The firms and other involved organizations respond to various obstacles and look for a way how to eliminate them. Individual deficiencies can be addressed by public or private interventions. The effectiveness of enablers of innovation activities is different. The effects of obstacles, enablers and firm innovation activity were analysed for knowledge-intensive German industries.

We found that the path P9 was the most consistent one, while path P4 had the largest coverage. On the other hand, path P9 uniquely covered the largest proportion of fuzzy set memberships. In this path, the interactions of all enablers led to the formation of positive cooperation and innovative effects. The results also suggest that enterprises following any of the identified paths are more innovative than their counterparts. Thus, we believe that the theoretical model of innovation paths was validated.

The results imply that it is necessary to further explore the various determinants of innovation activities and their interactions. The results of our study suggest that the determinants may not have the same effects in various industrial sectors, leaving a large proportion of the data uncovered by the extracted paths. It implies that public sector must define those public policies that will take into account the specifics of individual industries and will also lead to the combination of the determinants (enablers) with the greatest positive effects. For example, public funding was clearly associated only with educational knowledge sources (path P9) but internal, market and other knowledge sources seem to be of at least the same importance for the knowledge-intensive enterprises.

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