The effect of research and development personnel on innovation activities of firms: Evidence from small and medium-sized enterprises from the Visegrad Group countries

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A B S T R A C T
Objective: This study aims to assess whether research and development (R&D) personnel from firms, the research system, and governmental institutions contribute to innovation activities of firms from the Visegrad Group countries.
Research Design & Methods: Fixed effects panel regression with robust standard errors was used for hypothesis testing over the period 2009-2017. The data for the study was extracted from Eurostat, the European Innovation Scoreboard and the Organisation for Economic Cooperation and Development with a particular focus on R&D personnel from firms, the research system, and governmental institutions. The empirical analysis was focused on small and medium-sized enterprises (SMEs).
Findings: The results provide evidence about significant linkage between R&D personnel from governmental institutions and innovation activities of firms from the Visegrad Group countries. The research also highlights the lack of a significant effect of R&D personnel from firms and the research system on firms' innovation activities in the analysed former Soviet satellite economies distinguished by innovation performance below the average for the European Union.
Implications & Recommendations: Policy and practical implications that should be indicated include the necessity to further develop knowledge cooperation between governmental institutions and firms in order to reinforce innovation processes. There is also a need to enhance cooperation between the research system and firms to support SMEs from the Visegrad Group countries with highly-skilled human resources.
Contribution & Value Added: This article adds to the literature on drivers and sources of firms' innovation activities by providing new empirical evidence on the effect of R&D personnel on innovation activities of firms from the Visegrad Group countries, which are former Soviet satellite economies with a moderate level of innovativeness and belong to peripheral countries in the European Union.
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INTRODUCTION

A growing body of literature discusses and evaluates firms' innovation activities as crucial for the growth of firms, regions and countries (Fritsch *et al.*, 2020; Whitacre, 2019; Klewitz & Hansen, 2014). Because innovation activities affect many aspects of competitive advantages, explicit attention is paid to the sources and drivers of innovation processes (Frangenheim *et al*., 2020; Godlewska-Dzioboń *et al.*, 2019; Zygmunt J., 2017; Isaksen & Jakobsen, 2017; Edler & Fagerberg, 2017). One im-

portant strand of literature has highlighted the effect of knowledge diffusion on innovation performance of firms (Tijssen & Winnink, 2017; Frangenheim *et al.*, 2020; Rosenbusch *et al.*, 2011). Studies have found here a substantial role of knowledge networks between, among others, firms, the research system and governmental institutions (Thomas *et al.*, 2020; Rodríguez-Pose, 2013). The need to build knowledge networks to stimulate firms' innovation activities is based on theoretical arguments. According to knowledge spillovers and endogenous growth theories, the pivotal element for growth is innovation performance supported by efficient knowledge cooperation between firms, the research system, and governmental institutions (Audretsch & Belitski, 2020; Grillitsch *et al.*, 2019). Over the years, the rising relevance of knowledge cooperation has increased discussions about the involvement of research and development (R&D) in knowledge diffusion (Tijssen *et al.*, 2016; Asheim *et al.*, 2011). This is because R&D contributes to new knowledge creation (Odei *et al.*, 2020) and to innovation processes (Clausen, 2009). In line with this, research has noted that R&D is related to firms' innovation performance together with knowledge from diverse sources (Audretsch & Belitski, 2020) and should play a central role in knowledge diffusion processes (Huggins *et al.*, 2019). When considering the linkage between R&D, knowledge cooperation and innovation processes, the involvement of human resources cannot be neglected. This is especially vital since recent studies have indicated the effect of human resources involved with R&D on economic growth of countries and regions (Wang *et al.*, 2013; Tijssen & Winnink, 2017).

Prior studies suggest that R&D personnel from firms and from the research system may play an important role in effective knowledge diffusion (Teirlinck & Spithoven, 2013) leading to firms' innovation performance (Wang *et al.*, 2013). However, there is still little empirical evidence on the importance of R&D personnel from governmental institutions in encouraging firms' innovation activities (Raghupathi & Raghupathi, 2019). Furthermore, even though the earlier literature has dealt with the linkage between R&D personnel and firms' innovation performance, the empirical evidence concentrated mainly on countries with a high level of innovativeness (Tijssen *et al.*, 2016; Clausen, 2009). The question is whether the results of the previous studies also hold for countries with a moderate level of innovativeness. Concerning this, a lack of relevant studies was identified in relation to the Visegrad Group countries (Czechia, Hungary, Poland, and Slovakia) which are former Soviet satellite economies with innovation performance below the average for the European Union and belong to peripheral countries in the European Union. In this situation, whether R&D personnel affect innovation activities of firms from this group of countries is an attractive topic. To fill this gap, this article aims to assess whether R&D personnel from firms, the research system, and governmental institutions contributes to innovation activities of firms from the Visegrad Group countries. Fixed effects panel regression with robust standard errors allows testing the hypotheses. The empirical analysis relies on data from Eurostat, the European Innovation Scoreboard (2019, 2020), and the Organisation for Economic Cooperation and Development (OECD), and it concentrates on small and medium-sized enterprises. The research concerned the period 2009-2017.

This study contributes to the literature twofold. Firstly, the empirical evidence was tested for the Visegrad Group countries as former Soviet satellite economies. Concentrating on the Visegrad Group countries may bring substantial findings regarding similar innovation performance of these countries, which are below the average for the European Union (European Commission, 2020; European Commission, 2019) and belong to peripheral countries in the European Union. Secondly, the research shed more light on the relevance of human resources involved with R&D for innovation performance of firms.

This article proceeds as follows. The next section will discuss relevant literature on innovation activities of firms, knowledge diffusion, and R&D personnel. The following section will describe the data and variables used in the study and introduce the research method applied to recognise the significance of R&D personnel for innovation activities of firms from the Visegrad Group countries. The next section will report the results from the estimation of the panel regression model and robustness checks. This part will also present the discussion of the findings. The last section will conclude with the main policy and practical implications, limitations, and future research directions.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Recent studies have attracted considerable interest in the linkage between knowledge diffusion, R&D, and innovation activities of firms (Audretsch & Belitski, 2020; Lehnert *et al*., 2020; Tijssen *et al*, 2016). Some argue that knowledge diffusion focused on R&D, as crucial in building innovation potential of firms (Clausen, 2009), contributes to achieving a competitive advantage of firms and, consequently, the growth of countries and regions (Bilbao-Osorio & Rodríguez-Pose, 2011; Tödtling & Grillitsch, 2015). The growing theoretical and empirical body of work investigates here various aspects of knowledge networks related to R&D between, among others, firms, the research system and governmental institutions (Thomas *et al*., 2020; Isaksen & Jakobsen, 2017) as a triple helix essential for innovation processes (Thomas *et al.*, 2020). Most of these studies focused, among other things, on the effect of patents (Tijssen & Winnink, 2017), co-publications (Tijssen *et al*., 2016), or the educational level of human resources (Hauser *et al*., 2018, Baptista *et al.*, 2015) on firms' innovation performance. Policy instruments encouraging R&D and innovation processes have also attracted the attention of many scholars referring to, among others, R&D expenditures (Bianchini *et al*., 2019; Bilbao-Osorio & Rodríguez-Pose, 2011; Clausen, 2009; Hunady *et al.*, 2017). The discussion on the importance of knowledge networks and firms' innovation activities raises questions about the role of human resources associated with R&D in knowledge diffusion (Huggins *et al.*, 2019; Rodríguez-Pose, 2013; Wang *et al*., 2013; Tijssen & Winnink, 2017). In this regard, recent research argues that human resources associated with R&D (R&D personnel), as highly-skilled workers involved directly with the processes related with innovation (Wang *et al*., 2013), may provide essential support to firms' innovation performance (Bianchini *et al*., 2019). Such research became in recent years part of the debate on the relation between knowledge networks and innovation performance of firms (Lehnert *et al*., 2020). That research also motivates and guides this study by providing a basis for analysing the effect of R&D personnel on firms' innovation activities.

Considering the role of human resources associated with R&D in firms' innovation performance, there is a need to broadly define R&D personnel. Consistent with this, the study comprises both personnel directly related with R&D and personnel supporting R&D processes as administrative and office staff and managers (Raghupathi & Raghupathi, 2019; Eurostat, 2020). Furthermore, on the basis of the assumption that combining knowledge from different sources, related to the triple helix, is crucial for firms' innovation activities (Bianchini *et al*., 2019), there is a strong theoretical reason to assume that firm's innovation processes require not only firms' R&D personnel but also the R&D personnel from the research system and from governmental institutions (Asheim *et al*., 2011). For this reason, this research focuses on the R&D personnel from firms, the research system, and government institutions. Such an approach is in line with knowledge spillovers and endogenous growth theories that indicate the need for efficient knowledge cooperation between firms, the research system, and governmental institutions to develop innovation processes and achieve the growth of regions and countries. These theories also offer a relevant ground for this study, allowing for the analysis and interpretation of the results.

The analysis of studies indicates that in the context of the R&D personnel, there are relatively few empirical studies concerning directly R&D personnel in relation to firms' innovation performance. In this regard, especially R&D personnel from firms and from the research system have received attention, with relatively little consideration of R&D personnel from governmental institutions. It is also observed that empirical studies provide ambiguous results. Considering R&D personnel from firms, Teirlinck and Spithoven (2013) posit that such human resources became a crucial driver of firms' innovation activities. Recent works highlight especially the relevance of the quality of firms' human resources associated with R&D (Wang *et al*., 2013), arguing that firms should create conditions for building the R&D personnel capacity to support the process of knowledge diffusion (Solheim *et al*., 2020; Sauermann & Cohen, 2010). For instance, the rank of developing entrepreneurial attitudes of the R&D personnel is seen as a key to strengthening the R&D potential of firms (Wang *et al*., 2013). This corresponds to regarding firms' highly-skilled personnel as bringing knowledge for encouraging innovation performance (Isaksen & Jakobsen, 2017), suggesting a positive effect on innovation activities of firms,

and, consequently, regions' and countries' growth (Audretsch & Belitski, 2020; Solheim *et al.*, 2020). In this context, Raghupathi and Raghupathi (2019) analyse the relationship between country-level innovation in both OECD member and non-member countries and R&D processes and provide empirical results indicating a positive relation between firms' R&D personnel and innovation performance of firms. Similarly, Teirlinck and Spithoven (2013) have linked positively the qualifications and training of R&D personnel with innovation processes in small and medium-sized enterprises from Belgium (Teirlinck & Spithoven, 2013). This research highlights that personnel directly related with R&D, research managers, and personnel with second-stage tertiary education are necessary for knowledge diffusion and firms' innovation performance (Teirlinck & Spithoven, 2013). Lehnert, Pfister, and Backes-Gellner (2020) also suggest that firms' human resources associated with R&D positively affect firms' innovation activities. In this respect, conducted research on Swiss firms allows stating that firms' R&D personnel with tertiary education could positively affect innovation processes (Lehnert *et al.*, 2020). Furthermore, a positive relationship between R&D personnel of firms and firms' innovation performance is claimed by Koschatzky,, Bross and Stanovnik (2001) with regard to Slovenian firms from different sectors.

The lack of unambiguous results is noticeable in the research discussing how the R&D personnel from the research system affect innovation activities of firms. The debate points to an essential role of the research system, referring to universities and research organisations, in providing highly-skilled personnel (Isaksen & Jakobsen, 2017; Audretsch & Belitski, 2020). From this point of view, an understanding is emerging that human resources with tertiary and second-stage tertiary education, provided especially by the research system, are highly relevant to firms' innovation processes (Hauser *et al.* 2018, Baptista *et al.*, 2015). However, the research system encourages firms' innovation processes not only thought supporting firms with high-quality human resources. Following the literature on knowledge spillovers and endogenous growth, the research system is also believed to contribute knowledge crucial for fostering firms' competitive advantage (Lehnert *et al.*, 2020) through providing of the R&D research results (Thomas *et al.*, 2020). Therefore, there exists a considerable number of studies focusing on various forms of knowledge networks between the research system and firms (Huggins *et al.*, 2019). Growing attention is focused especially on patents as the results of firms' capability to absorb of knowledge from the research system (Tijssen & Winnink, 2017). Apart from patents, some studies suggest the role of co-publication in enhancing firms' innovation performance as a result of effective knowledge diffusion (Tijssen *et al.*, 2016). Following the premise that the research system is regarded as an important participant of knowledge networks supporting firms' innovation activities (Tödtling & Grillitsch, 2015), researchers are regarded as a crucial contributor of R&D. The results of the literature analysis indicate here the significance of the research system personnel involved with applied R&D rather than basic research and suggest a positive link between the R&D personnel from the research system and innovation activities of firms (Asheim *et al.*, 2011). In this context, Asheim, Moodysson, and Tödtling (2011) show that the research system personnel connected with R&D are found to be positively linked with innovation performance of firms. On the other hand, estimating "R&D excellence" as the capability of scientific research to develop of innovative technologies, Tijssen and Winnink (2017) recognise that the R&D personnel from the research system are not significantly correlated with firms' innovation performance. Accordingly, the research of Raghupathi and Raghupathi (2019) also found the lack of a significant linkage between the R&D personnel from the research system and innovation activities of firms.

Although existing studies mainly focus on knowledge diffusion between the research system and firms, the role of governmental institutions in innovation processes could not be overlooked. It results from the fact that governmental institutions affect firms' competitiveness and, consequently, the growth of regions and countries (Fitjar *et al.*, 2019). Thus, scholars have extended the focus on the capability of the government to create favourable conditions for innovation performance of firms (Rodríguez-Pose & Di Cataldo, 2015; Cortinovis *et al.*, 2017). The analysis of the literature highlights at least two areas in which governmental institutions are regarded as an essential participant of knowledge networks. Firstly, governmental institutions are attached great importance since providing policy instruments is pivotal for encouraging innovation activities of firms (Frangenheim *et al.*, 2020).

In this context, studies suggest that national and regional policies are crucial in assisting firms' innovation performance by providing background for R&D (Whitacre, 2019; Edler & Fagerberg, 2017) through suitable services and public goods (Isaksen & Jakobsen, 2017; Bianchini *et al.*, 2019). Secondly, governmental institutions are regarded as an important supplier of firms' highly-skilled human resources through creating conditions for accessibility of knowledge and education (Fitjar *et al.*, 2019; Rodríguez-Pose & Di Cataldo, 2015; Bianchini *et al.*, 2019). As studies have consistently found a linkage between governmental institutions and innovation processes (Rodríguez-Pose, 2013), a new question arises about the significance of R&D personnel from governmental institutions in knowledge diffusion and innovation performance of firms. The analysis of the literature leads to the conclusion that this question has received surprisingly little attention so far. Compared to the research on R&D personnel from firms and research system, empirical studies related to R&D personnel from governmental institutions remain scant. Empirical evidence is limited but supports the view that personnel from governmental institutions dealing with R&D may have a positive effect on firms' innovation activities. Such a relation has been recognized by Raghupathi and Raghupathi (2019). Similarly, Bianchini, Llerena, and Martino (2019) studying public support for Spanish firms suggest a positive linkage between human resources of governmental institutions associated with R&D and innovation processes.

The described background helped to highlight the importance of further research on the R&D personnel and firms' innovation performance. Firstly, the studies suggest that there is an ongoing concern to comprehend how R&D personnel affect firms' innovation performance. Secondly, the knowledge spillovers and endogenous growth theories provide ground for explaining the effect of R&D personnel on firms' innovation activities. Next, existing studies mainly focus on the linkage of the R&D personnel from firms, the research system, and innovation processes, whereas less attention has been devoted to the relationship between the R&D personnel from governmental institutions and innovation activities of firms. This offers a relevant ground for further research. There is also a noticeable lack of unambiguous results concerning the role of R&D personnel in innovation activities of firms. In line with this, the effect of human resources associated with R&D on firms' innovation performance is seen as an emerging research field. Furthermore, the analysis of the previous studies reveals various measurements both of R&D personnel and of innovation activities of firms. In this regard, some scholars use a percentage of R&D personnel in the business enterprise sector in active population, a percentage of the R&D personnel in the higher education sector in active population or a percentage of the R&D personnel in the government sector in active population to study the relationship between R&D personnel and firms' innovation performance. However, in this respect, other studies apply, among others, a percentage of the R&D personnel in the total number of workers or percentages of workers with a university degree. When considering innovation activities of firms, previous research adopts, for example, such measures referring to innovators construed as firms with product or processes innovation. Such research concerned firms of different sizes operating in various sectors, with data basically sourced from publicly available databases. Other studies, on the other hand, employed a survey method with a binary indication of firms' innovation performance. This implies the need for further research on the relationship between R&D personnel and firms' innovation activities. Furthermore, recent studies refer mainly to countries with a high level of innovativeness, while only few studies concern countries with a moderate level of innovativeness. Thus, it seems important to carry out further research to investigate how R&D personnel affect firms' innovation activities in such countries in order to verify whether the results also hold for countries with a moderate level of innovativeness. Following this gap, the question arises if the results hold for the Visegrad Group countries as the countries with innovation performance below the average for the European Union. However, despite expanding literature and empirical evidence on drivers and sources of innovation performance of firms from this group of countries (Wielechowski *et al.*, 2021; Zygmunt A., 2020; Paliokaitė, 2019; Hunady *et al.*, 2017), relatively little is known about the importance of human resources related to R&D for firms' innovation activities in Czechia, Hungary, Poland, and Slovakia. This study focuses on the Visegrad Group countries to address this gap and investigate the relation between R&D personnel from firms, from the research system and from governmental institutions and innovation activities of firms in these countries with innovation performance below the average for the European Union. This group

of countries also represents former Soviet satellite economies. Such economies are distinguished by a relationship between foreign direct investment and knowledge diffusion and firms' innovation processes (Hardy *et al.*, 2011). The Visegrad Group countries belong also to peripheral countries in the European Union. Because peripheral countries are distinguished by R&D expenditures that are greater for the public and universities sectors than for the private sector and are relatively less inclined to firms' innovation and have relatively underdeveloped knowledge networks (Rodriguez-Pose, 2014), the study relating to the Visegrad Group countries may provide new insight on sources and drivers of innovation processes. It is expected that there exists a positive effect of R&D personnel from firms, the research system, and governmental institutions on innovation performance of firms from the Visegrad Group countries.

Thus, the hypotheses of this research are stated as follows:

H1: Firms' R&D personnel positively contribute to innovation activities of firms from the Visegrad Group countries.

H2: The R&D personnel from the research system positively contribute to innovation activities of firms from the Visegrad Group countries.

H3: The R&D personnel from governmental institutions positively contribute to innovation activities of firms from the Visegrad Group countries.

RESEARCH METHODOLOGY

Data

The aim of this study is to assess whether the R&D personnel from firms, the research system, and governmental institutions contribute to innovation activities of firms from the Visegrad Group countries. Since SMEs play a vital role in the growth of the European Union's regions and countries (Rosenbusch *et al.*, 2011), representing 99% of the European Unions' firms (European Commission, 2021), this study focuses on small and medium-sized enterprises. The data used to carry out this research were retrieved from various sources of data. The primary data source was Eurostat as a database gathering information on the European Union member states. Eurostat was used to supply data about R&D and drivers of firms' innovation activities in the Visegrad countries such as: the R&D personnel from firms, the research system, and governmental institutions, R&D expenditures, education level of human resources, economic growth. Secondly, the European Innovation Scoreboard (2019, 2020) was used as database providing information about innovation performance of member states of the European Union. The European Innovation Scoreboard provides set of data on innovative firms in Czechia, Hungary, Poland, and Slovakia. The employed data set allows identifying whether R&D personnel support innovation activities of firms from the Visegrad Group countries.

Variables

In this research, three dependent variables were adopted to measure innovation activities of firms' from the Visegrad Group countries (*SME_INNOV*): (i) percentage of small and medium-sized enterprises with product or process innovation (*SME_INNOV_PROD_PROC*), (ii) percentage of small and medium-sized enterprises with marketing or organisational innovation (*SME_INNOV_MARK_ORG*), (iii) percentage of small and medium-sized enterprises with in-house innovation (*SME_INNOV_IN_HOUSE*). Such measurements of firms' innovation activities result from the analysis of previous research which indicates a lack of unambiguous specification of how to express innovation performance of firms. Here, previous studies refer to, among others, firms of different sizes and sectors, with product or processes innovation. Regarding the importance of SMEs in the growth of the European Union's regions and countries (Rosenbusch *et al.*, 2011), this research concentrates on small and medium-sized enterprises. Following the approach of Żelazny and Pietrucha (2017) and the European Commission to the differentiation of innovation performance (Żelazny & Pietrucha, 2017; European Commission, 2020), this research also adopts a broad approach to define firms' innovation activities. This approach comprises a diverse nature of innovation performance of firms and includes innovators construed as a percentage of SMEs with product or processes innovation and a percentage

of SMEs with marketing or organisational innovation and a percentage of SMEs with in-house innovation (European Commission, 2020a). Applying this approach allows for indicating the relationship between R&D personnel and firms' innovation performance associated not only with technological innovation, but also with non-technological innovation. While technological innovation are perceived to be related with a predominantly higher level of firms' innovation activities (expressed as product or processes innovation related to the introduction of at least one new or significantly improved product or process to a firm on market and in-house innovation related to a new or significantly improved product or process innovated in house), non-technological innovation (expressed as the introduction of at least one new marketing concept or organisational method) illustrate innovation activities of many firms related particularly to services sectors (European Commission, 2020b). Considering the above, this study adopts the measurements of innovation activities of firms in accordance with the European Innovation Scoreboard (2019, 2020). The independent variables expressed the R&D personnel, addressing Asheim, Moodysson, and Tödtling's (2011) and Teirlinck and Spithoven's (2013) argument that human resources involved in innovation processes matter for innovation performance of firms. As posited earlier, previous studies imply various measurements of the R&D personnel. This research follows Raghupathi and Raghupathi (2019) approach to define human resources involved with R&D as a percentage of the R&D personnel in business, higher education and government sectors in active population. The advantage is that this approach considers not only the R&D personnel from firms, but also the R&D personnel from the research system and from governmental institutions. Therefore, following these authors' approach allows finding out more about the relationship between the R&D personnel and innovation activities of firms from the Visegrad Group countries. The relevance of the quality of firms' human resources was also included in the study as highly significant for firms' innovation processes. Based on these, to understand how the R&D personnel affect firms' innovation activities four independent variables were employed. The first of them, the R&D personnel in the business enterprise sector (*FIRM_R&D_PERSONNEL*), proxied by a percentage of the R&D personnel in business enterprise sector in active population, intends to measure the effect of firms' human resources involved in the R&D on innovation performance of firms (Teirlinck & Spithoven, 2013). The next variable, the R&D personnel in the higher education sector (*HIGH_R&D_PERSONNEL*) allows investigating if the research system supports firms' innovation performance by offering cooperation with their the R&D personnel. This is in line with the evidence that cooperation between the research system and firms mainly concerns the R&D research rather than basic research (Asheim *et al.*, 2011). *HIGH_R&D_PERSONNEL* was calculated as a percentage of the R&D personnel in the higher education sector in active population. The third variable, the R&D personnel in the government sector (*GOVER_R&D_PERSONNEL*), intends to capture the importance of the R&D personnel from governmental institutions for innovation activities of firms (Bianchini *et al.*, 2019, Cortinovis *et al.*, 2017) as providing background for R&D. This variable was measured as a percentage of the R&D personnel in the government sector in active population. Since firms' innovation activities may be affected by highly-skilled human resources (D'Este *et al.*, 2014), the fourth independent variable (*TERITARY_EDUC*) was applied to capture the significance of human resources with tertiary education for innovation processes of firms (Lehnert *et al.*, 2020). *TERITARY_EDUC* was measured as percentage of population aged 25-34 with tertiary education.

The research also included two control variables with the aim of better isolating the effect of the R&D personnel on innovation activities of firms from the Visegrad Group countries as peripheral countries with innovation performance below the average for the European Union. As peripheral countries' R&D expenditures are greater for the public and universities sectors than the private sector (Rodriguez-Pose, 2014), gross domestic expenditure on R&D in the enterprise sector *(GERD)* was introduced to the research to verify whether the Visegrad Group countries are less inclined to firms' innovation. Because previous studies have found a close correlation between gross domestic expenditure and economic growth of firms and countries and regions (Tijssen & Winnink, 2017), it is expected that *GERD* positively influences the importance of the R&D personnel for firms' innovation performance. This variable was measured as gross domestic expenditure in the enterprise sector in EURO per inhabitant. The next control variable introduced to the study expresses gross domestic

product (*GDP*). As many scholars have found that GDP is related to economic development of firms, countries, and regions (Cortinovis *et al.*, 2017), this variable allows for controlling for economic conditions of the Visegrad Group countries and the capability of human resources involved with R&D to affect innovation activities of firms. The *GDP* was measured as gross domestic product per capita in PPS. Table 1 displays the main statistics related to the variables.

Table 1. Presentation of variables' statistics

Variables	Mean	Standard Deviation	Minimum	Maximum
FIRM_R&D_PERSONNEL	0.36	0.21	0.08	0.76
HIGH_R&D_PERSONNEL	0.28	0.07	0.16	0.40
GOVER_R&D_PERSONNEL	0.17	0.05	0.02	0.26
TERITARY_EDUC	31.71	6.46	20.20	43.60
GERD	82.94	49.99	15.70	204.00
GDP	74.17	8.58	60.00	91.00

Source: own study.

Research method

Panel regression is a method commonly used to estimate the relationship between knowledge diffusion, R&D, and innovation performance (Raghupathi & Raghupathi, 2019; Rodríguez-Pose & Di Cataldo, 2015) as it offers, among others, a greater ability to uncover the relationships between variables (Hsiao, 2007). A potential limitation of this method is related to the number of unknown parameters, which increase with the number of observations (Hsiao, 2007). To examine whether the R&D personnel affect innovation activities of firms from the Visegrad Group countries, fixed effects panel regression with robust standard errors was employed. The research concerned the period 2009-2017.[1] Empirical analysis focused on SMEs. The model used for the study was as follows:

$$\begin{aligned} SME\_INNOV_{it} = FIRM\_R\&D\_PERSONNEL_{it}\beta_1 + HIGH\_R\&D\_PERSONNEL_{it}\beta_2 \\ + GOVER\_R\&D\_PERSONNEL_{it}\beta_3 + TERITARY\_EDUC_{it}\beta_4 + GERD_{it}\beta_5 \\ + GDP_{it}\beta_6 + \alpha_i + e_{it} \end{aligned} \quad (1)$$

with one cross-section dimension *i* for the Visegrad Group countries (Czechia, Hungary, Poland, and Slovakia) and with one time dimension *t*=2009,…, 2017.

For the purpose of empirical analysis, three models were estimated for various dependent variables. Previously, following Raghupathi and Raghupathi (2019), the data for panel analysis was analysed to detect the stationarity of and multicollinearity among the variables. Stationarity was checked using the Kwiatkowski-Phillips-Schmidt-Shin test (KPSS). Multicollinearity among the variables was verified with the variance inflation factor (VIF). To explore the potential autocorrelation the Wooldridge test was used. The heteroscedasticity was tested applying the Wald statistic.

RESULTS AND DISCUSSION

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The effects indicated a lack of stationarity for all variables. Thus, there was a need to log the values of variables used in the research. The results of the variance inflation factor emphasised a high correlation between certain variables (Table 2).

Since some VIFs were higher than 10, confirming multicollinearity (Raghupathi & Raghupathi, 2019), the elimination of selected variables and repetition of the VIF test was necessary. After the removal of *log GERD*, all VIFs were lower than 10 indicating that multicollinearity was not an issue in this research (Table 3).

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[1] Since the last European Innovation Scoreboard 2021, firms' innovation activities have started to be defined differently from how they where classified in the earlier European Innovation Scoreboards. The inclusion to the study of the data from the last European Innovation Scoreboard 2021 would entail the lack of comparability and relevance of the results. Therefore, the study applied the latest data about firms' innovation activities from the European Innovation Scoreboard (2019, 2020), referring to the period 2009-2017.

Table 2. Effects of multicollinearity estimation

Variables	SME_INNOV_ PROD_PROC	SME_INNOV_ MARK_ORG	SME_INNOV_ IN_HOUSE
log FIRM_R&D_ PERSONNEL	21.215	21.215	21.215
log HIGH_R&D_ PERSONNEL	7.093	7.093	7.093
log GOVER_R&D_ PERSONNEL	3.034	3.034	3.034
log TERITARY_EDUC	1.629	1.629	1.629
log GERD	21.803	21.803	21.803
log GDP	10.549	10.549	10.549

Source: own study.

Table 3. Effects of multicollinearity estimation after elimination of selected variables

Variables	SME_INNOV_ PROD_PROC	SME_INNOV_ MARK_ORG	SME_INNOV_ IN_HOUSE
log FIRM_R&D_ PERSONNEL	5.030	5.030	5.030
log HIGH_R&D_ PERSONNEL	7.076	7.076	7.076
log GOVER_R&D_ PERSONNEL	3.012	3.012	3.012
log TERITARY_EDUC	1.585	1.585	1.585
log GDP	9.636	9.636	9.636

Source: own study.

Table 4 reports the results for fixed effects panel regression with robust standard errors, investigating the effect of the R&D personnel on innovation activities of firms from the Visegrad Group countries. These results concerned three models with various measurements of firms' innovation activities.

Table 4. The results for fixed effects panel regression with robust standard errors

Specification	Model 1 (SME_IN-NOV_ PROD_PROC)	Model 2 (SME_IN-NOV_ MARK_ORG)	Model 3 (SME_IN-NOV_ IN_HOUSE)
const	1.122	0.892	2.090
	(1.344)	(0.639)	(1.421)
log FIRM_R&D_PERSONNEL	0.080	0.025	0.085
	(0.096)	(0.036)	(0.113)
log HIGH_R&D_PERSONNEL	0.256	0.067	0.049
	(0.275)	(0.192)	(0.313)
log GOVER_R&D_ PERSONNEL	0.067	0.162*	0.049
	(0.085)	(0.063)	(0.095)
log GDP	1.714*	1.098**	2.248**
	(0.623)	(0.306)	(0.653)
log TERITARY_EDUC	0.373	0.969***	0.452
	(0.175)	(0.079)	(0.193)
p-value for test F	0.009	0.004	0.003
LSDV R-squared	0.825	0.828	0.835
Within R-squared	0.822	0.823	0.833
Observations	171306	193670	146359
Autocorrelation	YES	NO	YES
Heteroscedasticity	YES	NO	YES

Note: *** $p \leq 0.01$; ** $p \leq 0.05$; * $p \leq 0.10$.
Source: own study.

Since Model 1 (*SME_INNOV_ PROD_PROC*) and Model 3 (*SME_INNOV_ IN_HOUSE*) were distinguished by autocorrelation and heteroscedasticity, there was a need to exclude these two models from further analysis. As a consequence, technologically innovative SMEs from the Visegrad Group countries were excluded from further analysis. In relation to Model 2 (*SME_INNOV_ MARK_ORG)*, the

coefficient of determination (*LSDV R-squared*=0.828) was adequate to explain innovation performance of SMEs from the Visegrad countries representing non-technological innovation. The results showed that the coefficients of the R&D personnel from firms and from the research system were not significant, whereas the coefficient of the R&D personnel from governmental institutions was positive and significant. This suggests that the R&D personnel from firms and from the research system did not affect innovation activities of firms from the Visegrad Group countries. Such findings did not support Hypothesis 1 and Hypothesis 2 suggesting positive contribution of firms' and the research system's R&D personnel to innovation activities of firms from Czechia, Hungary, Poland, and Slovakia. Neither did these results fit with established theories indicating a pivotal role of efficient knowledge cooperation between firms and the research system in innovation performance. Furthermore, such observations are not consistent with the results of research by Teirlinck and Spithoven (2013) and Raghupathi and Raghupathi (2019) indicating that firms' R&D personnel is perceived as essential for innovation performance of firms. These findings are not in line with the effect of the studies by Asheim, Moodysson, and Tödtling (2011) either, pointing out a positive linkage between the R&D personnel from the research system and firms' innovation activities. On the other hand, lack of significant effect of the R&D personnel from the research system is in line with research by Raghupathi and Raghupathi (2019). This analysis suggests that contrary to the expectations, the R&D personnel from firms and from the research system do not affect innovation activities of firms from the Visegrad Group countries. Therefore, it is arguable that peripherality may cause insufficient involvement of highly-skilled personnel associated with R&D from firms and from the research system in firms' innovation performance. These outcomes conform to the argument of Rodriguez-Pose that peripheral countries are distinguished by a relatively slighter inclination towards firms' innovation and relatively underdeveloped knowledge networks (Rodriguez-Pose, 2014). This reflects the need to strengthen the cooperation between the research system and firms in the Visegrad Group countries. Furthermore, the lack of a significant relationship between firms' human resources associated with R&D and innovation activities of firms may result from insufficient conditions for firms to build the R&D personnel's capacity in order to support the process of innovation. The results showed a strong positive effect of the R&D personnel from governmental institutions on firms' innovation activities. This finding upholds Hypothesis 3 and is consistent with the discussion on the role of governmental institutions in knowledge diffusion, R&D and innovation performance of firms as presented by knowledge spillovers and endogenous growth theories and is similar to studies by Raghupathi and Raghupathi (2019) and Bianchini, Llerena, and Martino (2019). This proves that the R&D personnel from governmental institutions play an important role in innovation performance of firms from the Visegrad Group countries. Such findings suggest that national and regional policies in former Soviet satellite economies with a moderate level of innovativeness are crucial in assisting firms' innovation performance as they provide background for R&D and support innovation processes. The relative importance of governmental institutions in the Visegrad Group countries for firms' innovation activities is as expected for peripheral countries. The outcomes also indicate that the coefficient for human resources with tertiary education becomes positive and significant. This suggests that, as expected, human resources with tertiary education are linked positively with firms' innovation activities. Such findings emphasise the importance of highly-skilled human resources in enhancing innovation processes and, consequently, the growth of regions and countries. This evidence is in line with established theories and follows the studies by Lehnert, Pfister and Backes-Gellner (2020). This result implies that firms from the Visegrad Group countries benefit from human resources with tertiary education, even though the linkage between firms' R&D personnel as highly-skilled human resources and innovation activities of firms turns out to be not significant. This suggests that firms' policy is needed to improve skills of firms' R&D personnel and strengthen knowledge networks with the research system to get access to human resources with tertiary education. The results for control variables revealed that the coefficient for gross domestic product was as expected: positive and significant. The GDP is directly related to innovation processes, which is in line with the research by Cortinovis, Xiao, Boschma, and van Oort (2017). This finding highlights that economic conditions of the Visegrad Group countries support innovation activities of firms from Czechia, Hungary, Poland, and Slovakia.

Robustness Checks

To ensure the validity of the empirical results, research was replicated using three sets of panel regressions (related to three dependent variables) with slightly different independent variables than previously. Because the importance of human resources with tertiary education has been identified for innovation activities of firms from the Visegrad Group countries, a question arises about the role of human resources with second-stage tertiary education in innovation performance of firms from these former Soviet satellite economies with innovation performance below the average for the European Union. For this purpose, since highly-skilled human resources for firms' innovation activities were previously expressed by tertiary education, two new independent variables were applied: second-stage tertiary education graduates (*PHD_EDUC*) and foreign doctorate students (*FOREIGN_PHD_EDUC*). The first of them, *PHD_EDUC,* was employed to capture the influence of doctorate graduates on firms' innovation performance (Baptista *et al*., 2015), because personnel with a PhD are regarded as crucial in efficient knowledge diffusion (Teirlinck & Spithoven, 2013). This variable was measured as new PhD graduates per 1000 population at the age of 25-34. The data were retrieved from Eurostat. The second independent variable was applied following Leydesdorff, Wagner, and Bornmann's (2014) approach, according to which foreign doctorate students contribute to knowledge diffusion processes through providing external knowledge. This variable, measured as a percentage of foreign students in the total number of PhD students, reflects the relevance of high-quality human resources to innovation activities of firms. The data were collected from Eurostat. Table 5 presents descriptive statistics for the new independent variables.

Table 5. Presentation of new independent variables' statistics

Variables	Mean	Standard Deviation	Minimum	Maximum
PHD_EDUC	1.34	0.71	0.50	3.20
FOREIGN_PHD_EDUC	7.84	4.23	1.59	15.91

Source: own study.

The analysis of stationary properties of the new independent variables suggests a lack of stationarity of *PHD_EDUC* indicating the necessity to log the values of this variable. Because new independent variables were included in the model, some VIFs appear higher than 10 highlighting multicollinearity (Table 6).

Table 6. Effects of multicollinearity estimation

Variables	SME_INNOV_ PROD_PROC	SME_INNOV_ MARK_ORG	SME_INNOV_ IN_HOUSE
log FIRM_R&D_PERSONNEL	7.220	7.220	7.220
log HIGH_R&D_PERSONNEL	7.294	7.294	7.294
log GOVER_R&D_PERSONNEL	3.396	3.396	3.396
log PHD_EDUC	5.480	5.480	5.480
FOREIGN_PHD_EDUC	7.516	7.516	7.516
log GDP	10.257	10.257	10.257

Source: own study.

This meant the need for elimination of selected variables and repetition of the VIF test. Since *log GDP* was removed from the model and the variance inflation factor was repeated, all VIFs were lower than 10 (table 7).

As *log GDP* was eliminated, the model suffered from a lack of control variables. To address this issue and to ensure the effect of the analysis, new control variables were applied. Because patents are regarded as a driver of firms' innovation activities (Fritsch *et al*., 2020; Tödtling & Grillitsch, 2015; Raghupathi & Raghupathi, 2019), it was relevant to introduce PCT patent applications as a new control variable (*PCT PATENT*) to capture the influence of knowledge diffusion on innovation performance in peripheral countries distinguished by relatively underdeveloped knowledge networks (Rodriguez-Pose, 2014). *PCT*

PATENT was calculated as PCT patent applications per billion GDP. The data was retrieved from the European Innovation Scoreboard (2019, 2020). Foreign direct investment (*FDI*) was also applied as a new control variable due to firms' benefits from foreign knowledge (Bilbao-Osorio & Rodríguez-Pose, 2011). This variable indicates a relationship between foreign direct investment and knowledge diffusion and firms' innovation processes in former Soviet satellite economies. The *FDI* is measured as a percentage of foreign direct investment in relation to gross domestic product. The data was collected from the OECD database and Eurostat. Descriptive statistics for the new control variables are presented in Table 8.

Table 7. Effects of multicollinearity estimation after elimination of selected variable

Variables	SME_INNOV_ PROD_PROC	SME_INNOV_ MARK_ORG	SME_INNOV_ IN_HOUSE
log FIRM_R&D_ PERSONNEL	3.334	3.334	3.334
log HIGH_R&D_ PERSONNEL	2.478	2.478	2.478
log GOVER_R&D_ PERSONNEL	2.360	2.360	2.360
log PHD_EDUC	5.263	5.263	5.263
FOREIGN_PHD_EDUC	7.153	7.153	7.153

Source: own study.

Table 8. Presentation of new control variables' statistics

Variables	Mean	Standard Deviation	Minimum	Maximum
PCT PATENT	0.82	0.41	0.38	1.56
FDI	55.86	13.87	31.00	81.00

Source: own study.

The findings provide evidence about a lack of stationarity resulting in the necessity to log the values of variables. After the addition of the new control variables, the VIFs were lower than 10 showing that multicollinearity is not an issue in this research (Table 9).

Table 9. Effects of multicollinearity estimation

Variables	SME_INNOV_ PROD_PROC	SME_INNOV_ MARK_ORG	SME_INNOV_ IN_HOUSE
log FIRM_R&D_ PERSONNEL	5.946	5.946	5.946
log HIGH_R&D_ PERSONNEL	6.915	6.915	6.915
log GOVER_R&D_ PERSONNEL	2.398	2.398	2.398
log PHD_EDUC	7.599	7.599	7.599
FOREIGN_PHD_ EDUC	7.277	7.277	7.277
log PCT PATENT	7.348	7.348	7.348
log FDI	4.278	4.278	4.278

Source: own study.

The results indicated the lack of autocorrelation and heteroscedasticity of Model 5 (*SME_INNOV_MARK_ORG*). Thus, further analysis refered to SMEs from the Visegrad countries representing non-technological innovation. The coefficient of determination for Model 5 (*LSDV R-squared*=0.646) showed a sufficient explanation of innovation activities of firms from Czechia, Hungary, Poland, and Slovakia. The findings revealed that the coefficients for the R&D personnel from firms and from the research system were not significant, while the coefficient for the R&D personnel from governmental institutions was significant and positive. These results confirmed the main findings: the R&D personnel from firms and from the research system do not affect innovation activities of firms from the Visegrad countries, whereas the R&D personnel from governmental institutions do. As a result, only Hypothesis 3 was accepted. The findings demonstrated that personnel from governmental institutions dealing with R&D contributed to firms' innovation performance. These results imply that the Visegrad Group countries are the European Union peripheral countries where firms' innovation processes are more strongly stimulated by governmental institutions than by firms itself. Regarding second-stage tertiary education graduates and

foreign doctorate students, the results showed that the coefficients for these variables are not significant. These findings are not in line with the studies by Baptista, Frick, Holley, Remmik, Tesch and Âkerlind (2015), Teirlinck, and Spithoven (2013) and Leydesdorff, Wagner, and Bornmann (2014), which indicate the relevance of human resources with a PhD and foreign doctorate students for innovation processes. Such results emphasise that innovation activities of firms from the Visegrad countries are not affected by human resources with second-stage tertiary education. This suggests that the Visegrad countries, as former Soviet satellite economies with a moderate level of innovativeness suffer from still underdeveloped knowledge cooperation for effective knowledge diffusion. This suggests a necessity for further strengthening knowledge cooperation and knowledge diffusion to provide highly-skilled human resources with a PhD for the stimulation of firms' innovation processes.

Table 10. Robustness check. The results for fixed effects panel regression with robust standard errors

Specification	Model 4 *(SME_IN-NOV_PROD_PROC)*	Model 5 *(SME_IN-NOV_MARK_ORG)*	Model 6 *(SME_IN-NOV_IN_HOUSE)*
const	2.868***	2.114**	2.623**
	(0.385)	(0.404)	(0.471)
log FIRM_R&D_PERSONNEL	0.362*	0.062	0.358
	(0.147)	(0.238)	(0.156)
log HIGH_R&D_PERSONNEL	0.322	0.520	0.426
	(0.226)	(0.408)	(0.277)
log GOVER_R&D_ PERSONNEL	0.220**	0.423**	0.182*
	(0.051)	(0.082)	(0.059)
log PHD_EDUC	0.264	0.181	0.267
	(0.170)	(0.212)	(0.194)
FOREIGN_PHD_EDUC	0.004	0.004	0.011
	(0.010)	(0.014)	(0.012)
log PCT PATENT	0.039	0.141	0.055
	(0.099)	(0.233)	(0.096)
log FDI	0.625**	0.038	0.236
	(0.192)	(0.273)	(0.236)
p-value for test F	0.233	0.099	0.320
LSDV R-squared	0.819	0.646	0.819
Within *R-squared*	0.816	0.634	0.817
Observations	171306	193670	146359
Autocorrelation	YES	NO	YES
Heteroscedasticity	YES	NO	YES

Note: *** $p \leq 0.01$; ** $p \leq 0.05$; * $p \leq 0.10$.
Source: own study.

The outcomes indicated that the coefficients of both control variables were not significant. This reveals that patents and foreign direct investment are not linked with innovation activities of firms. This is different from the results by Fritsch, Titze, and Piontek (2020) and Bilbao-Osorio and Rodríguez-Pose (2011). Because patents are not related to innovation performance of firms from the Visegrad Group countries a question arises about the reasons for that. One of explanations is that Model 5, significant for the dependent variable depicting small and medium-sized enterprises with marketing or organisational innovation, may not directly depict patents as the results of innovation activities. In relation to foreign direct investment, the lack of a significant linkage with innovation performance of firms from the Visegrad Group countries indicates insufficient capabilities of conversion of foreign direct investment and, consequently, foreign knowledge to an increase in firms' innovation activities. Because former Soviet satellite economies are distinguished by the relationship between foreign direct investment and knowledge diffusion and firms' innovation processes, such insufficient capabilities may impact the growth of regions and countries. This implies the need for providing effective instruments to strengthen the impact of foreign direct investment on stimulating the innovativeness of firms from the Visegrad Group countries.

CONCLUSIONS

This article has investigated the drivers and sources of firms' innovation activities. Specifically, this study has addressed the relevance of human resources involved with R&D for firms' innovation activities referring to the ongoing discussion about the relationship between knowledge diffusion, R&D, and innovation processes. Special focus has been put on the R&D personnel from firms, from the research system and from governmental institutions, as essential for knowledge diffusion. The attention has been devoted to countries with a moderate level of innovativeness addressing a dearth of evidence in this field. In this regard, the study has concentrated on the Visegrad Group countries as former Soviet satellite economies, whose innovation performance is similar and below the average for the European Union and which belong to peripheral countries in the European Union. The empirical analysis has focused on small and medium-sized enterprises. This study contributes to the growing literature analysing the R&D personnel in relation to innovation processes by providing a new set of results. Applying fixed effects panel regression with robust standard errors, the study provides evidence about the lack of a significant relation between the R&D personnel from firms and from the research system and innovation activities of firms in the Visegrad Group countries. These results are important, because they raise questions about the insufficient involvement of highly-skilled personnel associated with R&D from firms and the research system in firms' innovation performance. The findings confirm that when it comes to the relationship between R&D and innovation performance, peripheral countries in the European Union feature a relatively slighter inclination towards firms' innovation and relatively underdeveloped knowledge networks (Rodriguez-Pose, 2014). The main results of this study are not in line with streams of literature and empirical evidence provided for countries with a high level of innovativeness (Teirlinck & Spithoven, 2013; Lehnert, Pfister & Backes-Gellner, 2020; Isaksen & Jakobsen, 2017; Audretsch & Belitski, 2020). Contrary to countries with a high level of innovativeness, in the analysed group of countries with a moderate level of innovativeness, human resources associated with R&D from firms and from the research system do not affect firms' innovation activities. Furthermore, human resources with second-stage tertiary education and foreign doctorate students appear not to be engaged with innovation activities of firms from the Visegrad Group countries. There emerges a need to strength knowledge cooperation between the research system and firms in the Visegrad Group countries in order to provide highly-skilled human resources. This work also expands scant studies on the role of human resources associated with R&D from governmental institutions in innovation processes (Raghupathi & Raghupathi, 2019), suggesting a significant and positive linkage of the R&D personnel from governmental institutions with firms' innovation performance.

The findings have implications for policymakers and for practice. Since the R&D personnel from governmental institutions have proven to be crucial for innovation performance of firms, there is a need to provide effective instruments to further strengthen and develop knowledge cooperation between governmental institutions and firms so as to further reinforce innovation processes. Considering the research system, the cooperation between the research system and firms should be strengthened in the Visegrad Group countries to support SMEs with highly-skilled human resources. The findings also suggest the necessity to enhance firms' conditions for building the R&D personnel's capacity to support the innovation process. Furthermore, the study shows the need to strengthen effective instruments that would allow for greater interactions between foreign direct investments and foreign doctorate students and reinforce innovation processes of firms from the Visegrad Group countries.

The research has some limitations that pose further questions to be addressed. Firstly, the study relies mainly on measures of variables and data from Eurostat and the European Innovation Scoreboard. For this purpose, it would be beneficial to use other measurements of the R&D personnel and firms' innovation activities to observe if the research would lead to similar results. Secondly, as the application of fixed effects panel regression with robust standard errors has resulted in the exclusion from the analysis of technologically innovating SMEs from the Visegrad Group countries, research should further investigate whether the obtained results would also be true if a different research method were applied. Future research should also focus on in-depth studies on the sources of a lack

of significant contribution by the R&D personnel from firms and from the research system to innovation performance of firms from the Visegrad Group countries.

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Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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