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Innovation barriers as triggers of firms' eco-innovations: The mediating role of public and market knowledge sourcing

Denys Dmytrenko , Fazal Ur Rehman and Viktor Prokop*

*Science and Research Centre, Faculty of Economics and Administration, University of Pardubice, Pardubice, Czech Republic

Abstract

This study expands the existing knowledge about the impact of innovation barriers on firms and tests whether such barriers stimulate their environmental behaviours. For these purposes, we focus on the specific region of Central Europe, which was considered lagging in previous years. It was caused, on the one hand, by the lower innovation performance of firms and states in comparison with their western neighbours, but also due to a lower environmental perception on the part of the whole society. By using data on 14,808 firms from three Central European countries (Czech Republic, Slovakia, and Hungary) and the Partial Least Square Structural Equation Modelling (PLS-SEM) method, this study contributes to the ongoing debate regarding the eco-innovation performance of the Central European territory, where such analyses are still rare. Our results show that firms facing innovation barriers tend to create eco-innovations. We confirm our expectation that Central European firms depend on external sources of knowledge acquired on the market. Moreover, we show that even public knowledge resources obtained from universities and research institutions support the creation of eco-innovations. These results allow us to propose several implications for practitioners and policymakers.

Keywords: innovation barriers; eco-innovation; Central Europe; knowledge, R&D

Conflict of interest: none

1. Introduction

The issue of sustainability is one of the key topics in modern research. The concept of sustainability is based on three pillars, one of which is the environment (Elkington, 1997). Environmental degradation is a significant problem in the world today, as it affects the economy, human health, and wildlife (Guo et al., 2022). To oppose the effects of environmental degradation, governments and supranational organizations introduce policies that oblige companies to behave more environmentally friendly (Jiménez-Parra et al., 2018). However, the production of material goods cannot be stopped because sustainability also has two other components: economic and social. Production is necessary, but old equipment and old methods of production must be replaced with new and more efficient ones in order to reduce emissions in manufacturing (Bossle et al., 2016). Therefore, eco-innovations are the major instrument in reducing human influence on the environment. A conventional innovation can be regarded as eco-innovation if its implementation leads to a reduction of the environmental burden (Horbach et al., 2012).

In the case of conventional innovations, companies that strive for innovations face several barriers to which they can react in different ways. Common innovation barriers include a lack of resources (financial or human) (Horbach et al., 2013; Hojnik and Ruzzier, 2016), a low degree of cooperation with research institutions (Cainelli et al., 2012), unwillingness to innovate by the management of the company (Ávila et al., 2017), and other. Given the presence of such barriers, firms can either refuse to innovate or try to overcome them. Overcoming barriers can be done, e.g., by attracting financial assets and knowledge from the outside and by strengthening the cooperation with external actors who possess the tools necessary for innovation. Barriers, which are typical for innovations in general, are also applicable in the case of eco-innovations (Horbach et al., 2012; Hojnik and Ruzzier, 2016). However, there are some distinctions, such as motivation, to implement them. Eco-innovations are a more externally driven type of innovation. (Pavez et al., 2020) The above-mentioned barriers can prevent or significantly hinder innovation processes in firms. In particular, Sanchez-Henriquez and Pavez (2021), who proved the positive impact of market knowledge on eco-innovations, recommended expanding the research to test the influence of innovation barriers. Marin et al. (2015) also mentioned that depending on the other factors, innovation barriers could either help or prevent firms from implementing eco-innovation.

Therefore, *our motivation in this paper is to find out whether firms facing innovation barriers tend to implement eco-innovations in Central European countries.* For the purpose of this study, we focus on the Central European (CE) countries because they were previously viewed as polluters and as those lagging behind Western European ones (Tokunaga, 2020; Jehlička and Jacobsson, 2021). According to Horbach (2016), CE countries have a lower degree of environmental awareness, are less eco-friendly, and are less keen on eco-innovations.

According to Silajdzic and Mehic (2017: 161), the authors state that (i) CE countries "*have less rigid environmental regulation compared with more developed EU countries*"; (ii) relaxed environmental registration is rather an advantage for firms in CE; and that "*relatively lax*" environmental policy within these territories could *"present a comparative advantage that may positively affect trade flows of pollution-intensive industries."* According to Botta and Kozluk (2014), who used OECD data on environmental stringency, CE countries used to have significantly lower levels of environmental policy stringency prior to the accession to the EU in 2004. Next, the study of Jug and Mirza (2005) confirms the distinct difference between environmental policy stringency in Central, Eastern, and Western Europe.

Furthermore, firms in the CE region tend to face more innovation barriers than countries in Western Europe because they have catching-up economies and, therefore, lower capacity for investments in newer technologies. Also, these countries were under socialist rule and had comparatively little experience of the market economy (Tokunaga, 2020). In addition, according to Jehlička and Jacobsson (2021), CE countries have so far been less researched in comparison with their western counterparts. Therefore, we identify a research gap regarding the research of this area, especially in relation to the eco-innovations of firms. At the same time, we see a high potential for research in this area, as it has been less researched so far.

Innovation barriers can motivate firms to seek additional resources to start innovation processes. Prokop et al. (2021) found that external knowledge from domestic sources is an important factor for innovation processes in Central European countries. *We also aim to test how these processes are affected by the acquisition of market and public knowledge sources, and this time for eco-innovations.*

Using data from the Community Innovation Survey and the PLS-SEM technique, our results show that innovation barriers are influential in boosting eco-innovations and research and development (R&D) activities in Central European firms. Besides that, R&D and external knowledge have a strong impact as mediating factors between innovation barriers and eco-innovations. Key findings of our study include the positive influence of innovation barriers on eco-innovations and R&D activities in Central European firms, the important role of public and market knowledge in fostering eco-innovations, and the significant influence of R&D as a mediating factor.

This study contributes to the current state of knowledge in the areas of eco-innovations and innovation barriers in the region of Central Europe, whose analysis is called for by several recent studies focusing on environmental performance in this area (Hojnik et al., 2022; Prokop et al., 2023). More specifically, we proved the positive relationship between innovation barriers and eco-innovation, discovered the significant role of R&D, and found an important difference between the effects of public and market knowledge. Another significant finding is that barriers pressurize toward R&D to a greater extent, which, in turn, boosts eco-innovations. Our conclusions are valuable because there is an ongoing debate as to whether such "traditional" innovation barriers prevent or stimulate firms' environmental behaviour and eco-innovation (Marin et al., 2015; Ávila et al., 2017). Furthermore, our results are important due to the lack of studies considering the Central European region (Jehlička and Jacobsson, 2021).

The rest of the paper is structured as follows. Section 2 contains an overview of the existing literature on the effects of innovation barriers on eco-innovation and on the role of R&D and external knowledge in the process of eco-innovation. Section 3 consists of methods and data descriptions. Next, we present the results and their discussion in Sections 4 and 5, respectively. In the last part, we conclude our paper by summarizing contributions, policy implications, and suggestions for future research.

2. Literature review and hypotheses

2.1 Innovation barriers, firms' R&D, and (eco) innovativeness

So far, the literature has identified various barriers to the innovation process of firms, including an emphasis on the barriers between innovators and non-innovators. According to Nečadová and Scholleová (2011), non-innovative companies cite the lack of resources as a main barrier to not conducting innovations, while innovative ones mention the unwillingness of their employees. Coad et al. (2016) also confirmed that a lack of financial resources and insufficient personnel qualifications are barriers to innovations in companies. Ávila et al. (2017), who studied barriers to innovation and sustainability in universities, concluded that management's attitude plays a crucial role in the implementation of innovations. D'Este et al. (2012) distinguish two types of barriers: revealed (known) and deterring. The former means the readiness of a firm to implement innovations, while the latter characterizes those who refuse to do it. Concerning the barriers to innovations and external knowledge, Torres de Oliveira et al. (2022) define the intensity (or depth) of the external knowledge connections of the enterprise as the crucial mediating factor in the relationship between innovation barriers and innovation performance.

Hojnik and Ruzzier (2016), who studied the barriers and drivers for eco-innovations, concluded that costs represent the most common internal barrier to eco-innovations. In contrast, the authors state that legislation is the most significant external barrier. According to Horbach et al. (2013), who studied the cases of Germany and France, unlike in other types of innovation, eco-innovations are stimulated by two factors: regulations and cost saving. Horbach et al. (2013) also found that eco-innovation turned out to rely more on external knowledge than other types of innovation. Hrabynskyi et al. (2017) confirm that eco-innovation is driven by reduced costs and regulations. The paper of Horbach et al. (2013) presents interest in our research because it also used a Community Innovation Survey. Kiefer et al. (2019), while testing the effect of internal and external factors on eco-innovations, found that ecological certification, lack of internal knowledge and cooperation, and technological path dependency are the main barriers to eco-innovations.

According to Marin et al. (2015), the difference between conventional innovations and eco-innovations is that the latter are driven not only by the market but also by policies. Regarding the drivers of eco-innovations, Horbach et al. (2012) cite three main sources of motivation for environmental innovations: government regulations, cost savings, and customer requirements. Authors find each of these three factors more or less significant, depending on the type of eco-innovation the company is performing. From another point of view, Horbach (2016) points out the lack of R&D investment as a crucial barrier to eco-innovations in Eastern Europe. The author compared Eastern European countries with Western European ones to prove that the latter ones have higher levels of eco-innovations due to higher levels of R&D expenditure. Szarowská and Žůrková (2017) and Krkošková (2019) point out the crucial impact of public R&D investment on other economic indicators in countries in Central Europe.

The first known study in which barriers were mentioned to have stimulating effects on innovation was conducted by D'Este et al. (2012). The authors defined two types of innovation barriers: deterring and revealed, with the former being an obstacle to innovation implementation and the latter being an incentive for innovation. The authors' analysis is based on data on firms' perceptions of the importance of barriers in their innovation activity. Marin et al. (2015) conducted research that mentioned known barriers, following the steps of D'Este et al. (2012), but this time considering specifically eco-innovation. Marin et al. (2015) found that firms tend to eco-innovate despite the presence of different types of barriers, and they perceive revealed barriers as rather an incentive. Pellegrino (2018) also used known barriers in his study, proving that, in the case of revealing barriers, they are not an obstacle to firms' innovation activity. However, none of the above-mentioned papers included an analysis of the direct and indirect effects of barriers on eco-innovation (they only studied the firms' management perceptions of barriers). Our study, to the best of our knowledge, is the first to look at the revealed barriers' real effect on eco-innovation activity within the firm.

Cheng and Shiu (2012) found a significant positive influence of the increase in R&D investment on eco-innovations. Therefore, cost, which is expressed in three out of seven innovation barriers used in our study, is mentioned as a key barrier (and motivation) for eco-innovations, especially in Central Europe. From here, based on the literature review and findings so far, we test whether and how innovation barriers affect firms' eco-innovation and R&D. We assume that innovation barriers could stimulate a change in firms towards more ecological innovations and, at the same time, stimulate R&D activities, which have been proven to be an important trigger of the environmental behaviour of CE firms (see Hojnik et al., 2022). Therefore, we hypothesize that (all proposed hypotheses are summarized in our conceptual framework; see Fig. 1):

H1*: Innovation barriers trigger firms' eco-innovation activities in Central Europe.*

H2*: Innovation barriers trigger firms' R&D in Central Europe.*

Since R&D is accepted as a determinant of firms' "general" innovations across CE countries (Klimova, 2018; Prokop et al., 2021), it is also necessary to focus on the relationship between R&D and firm's eco-innovations in the area we analyze. Research so far confirmed that R&D could be a significant trigger for firms' eco-innovation (Orlando et al., 2020; Dimakopoulou et al., 2022), enhancing their financial and environmental capabilities (Marín-Vinuesa et al., 2020). For example, Guisado-Gonzalez et al. (2021) show that R&D has positive effects on firms' performance and eco-innovation in Spain. Next, Ha et al. (2022) confirm that R&D significantly influences technological capabilities and eco-innovation among SMEs in Vietnam. However, considering the effects of R&D on firms' environmental performance within CE countries, Hojnik et al. (2022) show that these effects can be both significant and non-significant, leading to differences between countries. On the other hand, Hálásková and Bednář (2018) confirm the positive influence of total and public R&D activities (expenditures) on general innovations in the EU countries. Prokop and Stejskal (2019) discovered the positive effect of internal R&D on general innovation activities in small enterprises in Germany. We, therefore, see it as necessary to focus on these effects, and, at the same time, we expect rather positive effects of R&D on firms' eco-innovations as follows:

H3: *R&D has positive effects on firms' eco-innovation in Central Europe.*

2.2 Innovation barriers, external knowledge sources and (eco) innovation

Peterková et al. (2022) mentioned that the exploitation of external knowledge is crucial for companies' innovation performance. Ascani et al. (2020) noted that the ability to use external knowledge is a critical feature in the region's competitiveness and development. Audretsch and Belitski (2020) identified that knowledge spillovers are more important than R&D for a company's productivity. The authors noticed that US firms are more innovative than Europe's ones, in part due to wider usage of R&D and knowledge spillovers. Regarding the influence of knowledge on eco-innovations, Cainelli et al. (2012) cite lack of knowledge as one of the obstacles to eco-innovations; however, not the biggest one. Horbach (2016) indicated that Eastern European countries are more dependent on foreign sources of knowledge than Western European ones because the R&D expenditures per GDP there are below the average EU level. Frigon et al. (2020) concluded that eco-innovations rely more on external knowledge than conventional innovations in the Canadian wine industry. Sanni and Verdolini (2022) confirm this statement. Muscio et al. (2017) studied eco-innovations in the Italian wine industry and found that internal or external sources of knowledge have an effect, depending on the type of eco-innovation. Additionally, the authors discovered a positive correlation between the sourcing of external knowledge and eco-innovations. At the same time, knowledge is regarded as a positive spillover due to eco-innovation activities (Cainelli et al., 2012; Marin et al., 2015). According to Peri (2005), who analyzed European and North American regions, the knowledge flows used to be spread much further than trade flows, and domestic knowledge flows were much more common than flows from abroad. Even flows from other regions are rare, and most of them come from the same region. However, foreign knowledge flows are more common for the IT sector and leaders in the industries. Ghisetti et al. (2015) extended the open innovation concept to eco-innovations and defined that the absorptive capacity of the firm plays a crucial role in using external knowledge for eco-innovations. According to the authors, a deeper and broader variety of external knowledge sources help firms to implement eco-innovations.

However, there is a limit after which deepening and broadening of sources does not increase the ability of firms to eco-innovate. Sanni and Verdolini (2022) cite a lack of fit of external knowledge type to a firm's area as a barrier to eco-innovation. Therefore, as the authors state, the knowledge base of a firm must be diverse to be able to satisfy the need for eco-innovation. They also confirm the statement of Ghisetti et al. (2015) about the importance of the absorptive capacity of the firm. Triguero et al. (2022) found an inverted U-shaped correlation between the diversity of the external knowledge sources and the ability of firms to eco-innovate. It means that diversity helps until a certain point is reached. Marzucchi and Montresor (2017) discovered that synthetic external knowledge is more important for eco-innovations than analytical knowledge. Sanni and Verdolini (2022), referring to Yang and Lin (2012) and Ben Arfi et al. (2018), emphasize the importance of a combination of inbound and outbound knowledge. Eventually, the authors suggest that firms must use both analytical and synthetic external knowledge sources for more efficient eco-innovation strategies.

Considering the effects of firms' innovation barriers on their efforts to acquire external knowledge, Huggins et al. (2010) state that the cost of external knowledge is regarded as a noticeable innovation barrier. Martin and Moodysson (2011) put geographic distance as one of the main barriers to knowledge spillovers. Torres de Oliveira et al. (2022) list absorptive capacity (lack of skilled employees) and geographical distance (lack of cooperation partners) as the main innovation barriers related to knowledge sourcing. In this study, we follow the recommended approach of Hájek and Stejskal (2018) and distinguish between two types of external knowledge, namely public knowledge (represented by firms' cooperation with universities or other higher education institutes and government, public or private research institutes) and market knowledge (represented by firms' cooperation with suppliers, clients, competitors, consultants). Here, we expect that innovation barriers stimulate firms' need to seek new external knowledge, and we hypothesize that

H4a*: Innovation barriers trigger firms' sourcing of public knowledge in Central Europe.*

H4b*: Innovation barriers trigger firms' sourcing of market knowledge in Central Europe.*

Next, Cainelli et al. (2012) emphasize that cooperation with suppliers (market knowledge) and universities (public knowledge) is one of the most critical drivers for eco-innovations. Sanchez-

Henriquez and Pavez (2021) confirmed the positive influence of market knowledge on eco-innovations, while Chaparro-Banegas et al. (2023) proved the positive impact of public knowledge. There are few sources of public knowledge to increase innovation performance, such as public R&D institutions and universities. Some researchers have demonstrated a positive influence of research institutions and universities on eco-innovations. (Cainelli et al., 2012; Horbach, 2016) However, others (Sáez-Martínez et al., 2016) found a negative relationship between cooperation with research institutions and eco-innovations. In the case of public knowledge, we consider cooperation with public research institutions and universities. Orlando et al. (2020) and Long and Liao (2021) concluded that eco-innovation in firms is mainly supported by public investment, while private funding plays a minor role. Díaz-García et al. (2015) found that the R&D capacity of a firm has a positive effect on firms' innovations in general but not on eco-innovations. Chaparro-Banegas et al. (2023) found public R&D cooperation more beneficial for firms' eco-innovation activities than market R&D knowledge. In the case of eco-innovations, companies may not be willing to introduce new products or processes due to a lack of market demand for this type of innovation. It corresponds to one of the innovation barriers, which we use as an independent variable. Though, the motivation in the case of eco-innovations is different from conventional ones, and they depend more on public investment sources (Ociepa-Kubicka and Pachura, 2017). Based on the above-mentioned information, we hypothesize that:

H5a: *Public knowledge sourcing triggers firms' eco-innovation in Central Europe.*

According to Ardito et al. (2020), a firm's cooperation with suppliers increases its efficiency. Simao and Franco (2018) mention consultants as an important source of knowledge for eco-innovations, as they can share knowledge about the market and information from competitors with the firm. Eco-innovations are a unique type of innovation, for which companies may cooperate even with their competitors (Kiron et al., 2015). Because the goal of eco-innovations is, first of all, not to receive a competitive advantage but to reduce the negative effect on the environment, which benefits the whole society (Pavez et al., 2020; Zaman et al., 2022). Concerning R&D institutions, research shows that private R&D contributes to eco-innovations more than public ones (Jiménez-Parra et al., 2018). In summary, we also expect positive effects of market knowledge sourcing on firms' eco-innovation and hypothesize that:

H5b: *Market knowledge sourcing triggers firms' eco-innovation in Central Europe.*

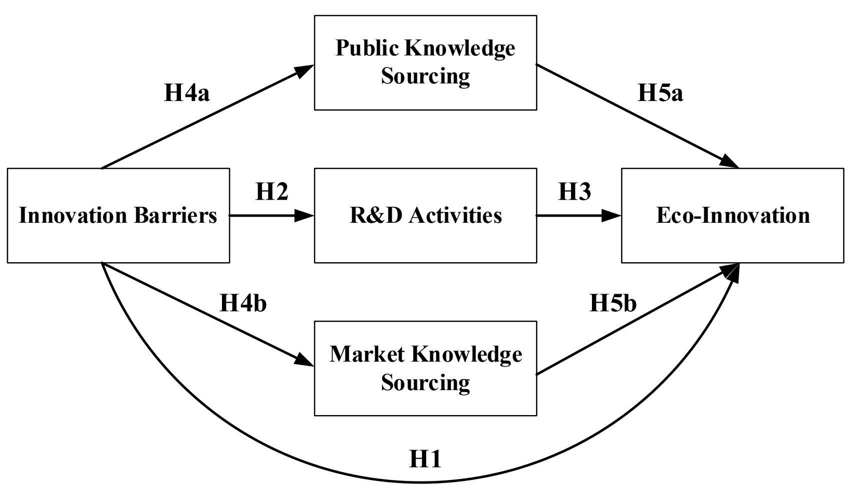

Figure 1. Conceptual framework

3. Data and method

3.1 Data and selected countries

We use the Community Innovation Survey, which is a survey on the topic of innovation in EU enterprises conducted by the European Commission. The Community Innovation Survey is helpful in identifying the determinants of eco-innovation and offers a separate module for eco-innovation, highlighting the developmental level, R&D inputs, energy intensity, and environmental concerns of the Eastern European countries (Horbach, 2016). The Community Innovation Survey presents information on the innovation activities of enterprises among the member states of the European Union (Leitner, 2018). We use the 2014 version of the survey, which is the latest available survey that contains data on eco-innovations and environmental behaviour of firms. We conducted our analysis on a sample of 14808 firms from three countries: the Czech Republic (5199 firms) Slovakia (2791 firms), and Hungary (6818 firms).

Despite the fact that these countries are seen as less interested in environmental issues (Prokop et al., 2023) and as the main polluters in Europe (together with their Eastern European neighbours), we can see several attempts by these states towards environmental behaviour. More specifically, the Czech Republic is widely focusing on adopting the environmentally friendly technologies, improving energy and resource efficiency, enhancing waste management, launching a sustainable transport system, and initiating eco-innovation approaches of products (Danube, 2018; Vokoun and Jílková, 2020; Costantini et al., 2023). In the same way, Slovakia has started the transition process and established a strong institutional support to enhance R&D activities and the initiatives of eco-innovation initiatives, improve long-term needs of the society, promote economic growth, and ecological innovation to achieve the objectives of sustainable development (Loucanova et al., 2015; Malega et al., 2021; Loučanová et al., 2022). In addition, Hungary has also widely initiated environmental innovation practices and eco-innovation activities in the public sectors, industry 4.0 technologies for operational excellence, and eco-efficiency for sustainable development (Széchy, 2012; Przychodzen and Przychodzen, 2015; Szalavetz, 2017). Due to the above reasons, this study focused on including the Czech Republic, Slovakia, and Hungary in a survey to understand the eco-innovation activities and clarify the association among the outlined variables. Karman et al. (2020) noted the difference between levels of eco-innovativeness across Europe, with lagging countries achieving convergence. Hajdukiewicz and Pera (2023) found the opposite trend in eco-innovation convergence in Europe. The authors argue that, despite the progress in the implementation of eco-innovation among low and average innovators in Europe, the gap between different groups of innovators remains big.

3.2 PLS-SEM

This study has applied the technique of Partial Least Square Structural Equation Modelling (PLS-SEM) to analyse the dataset. Usually, PLS-SEM follows the procedure of measurement model and structural model to validate and display the association among constructs (Tabachnick and Fidell, 2001; Hair et al., 2014). In particular, SmartPLS software (version 3.3.3) is widely perceived as an efficient tool for statistically analysing the covariance-based SEM rather than other statistical tools like AMOS (Rasool et al., 2023). PLS-SEM is a helpful source to test conjectures, develop theory, preferable in the multivariate analysis method, a variance-based SEM approach, display output in one click, and authenticate the association among constructs in a systematic manner (Rehman and Prokop, 2023; Hussain et al., 2023). PLS-SEM has the advantage of evaluating the association among constructs in the complex models, can handle the issues of normality, is less sensible about sample size, multicollinearity, etc., and is preferable in the formative theoretical consideration (Tabachnick and Fidell, 2001; Henseler and Sarstedt, 2013; Hair et al., 2014). For these reasons, PLS-SEM was the suitable option to examine the relationship among constructs in the defined model. Hence, the defined model has the following equations to follow:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + i \quad (1)$$

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + i \quad (2)$$

Where Y is the eco-innovation (dependent variable), β_0 is the regression coefficient (constant), β_1, β_2… are the regression beta values, X_1 is the innovation barrier, X_2 is R&D, X_3 is the public knowledge, X_4 is the market knowledge, and ϵ_i is the error or residual (Equation (1)). Likewise, X_5 is the addition of environmental policies, while X_6 is the addition of public finance as a control variable in (Equation (2)) for the assessment of the second model. In **Table 1,** we provide the statistics for the variables that, in particular, constitute each of the variables in complex, namely Barriers, Research & Development, Public Knowledge, and others.

Table 1. Description of the Variables

Construct	Description
Barriers	Lack of internal finance for innovation
	Lack of credit or private equity
	Lack of skilled employees within your enterprise
	Difficulties in obtaining government grants or subsidies for innovation
	Lack of collaboration partners
	Uncertain market demand for your ideas for innovations
	Too much competition in your market
Research & Development	Research and development activities undertaken by your enterprise to create new knowledge or to solve scientific or technical problems (including software development in-house that meets this requirement)
	Your enterprise contracted-out R&D to other enterprises (include enterprises in your own group) or to public or private research organizations
	Acquisition of advanced machinery, equipment, software, and buildings to be used for new or significantly improved products or processes
	Acquisition of existing know-how, copyrighted works, patented and non-patented inventions, etc. from other enterprises or organizations for the development of new or significantly improved products and processes
	In-house or contracted out training for your personnel specifically for the development and/or introduction of new or significantly improved products and processes
	In-house or contracted out activities for the market introduction of your new or significantly improved goods or services, including market research and launch advertising
	In-house or contracted out activities to alter the shape, appearance, or usability of goods or services
Public Knowledge	Universities or other higher education institutes
	Government, public or private research institutes
Market Knowledge	Suppliers of equipment, materials, components, or software
	Clients or customers from the private sector
	Competitors or other enterprises in your sector
	Consultants or commercial labs
Eco-Innovation	Reduced material or water use per unit of output
	Reduced energy use or CO_2 footprint (reduce total CO_2 production)
	Reduced air, water, noise, or soil pollution
	Replaced a share of materials with less polluting or hazardous substitutes

	Replaced a share of fossil energy with renewable energy sources
	Recycled waste, water or materials for own use or sale
	Extended product life through longer-lasting, more durable products
Controls	
Environmental Policies	Existing environmental regulations
	Existing environmental taxes, charges, or fees
	Environmental regulations or taxes expected in the future
	Government grants, subsidies or other financial incentives for environmental innovations
Public Finance	Local or regional authorities
	Central government (including central government agencies or ministries)
	The European Union (EU)

We also have two control variables: environmental policies and public finance. These variables were used, in particular, by Hojnik and Ruzzier (2016) and Triguero et al. (2022). These are the two instruments that governments can apply in order to stimulate eco-innovation in private firms, and they represent punishing and incentive measures, respectively.

4. Results

4.1 Measurement Model

The current study has evaluated the data file using the technique of PLS-SEM to find the results of the proposed theoretical settings. Usually, the measurement model and the structural model are the main drivers in the PLS-SEM analysis to validate the conceptual model and display the image of the results (Zeb et al., 2021; Rasool et al., 2023). The measurement model evaluates factors loading (>0.7), composite reliability (>0.7), AVE (>0.5), discriminant validity, and HTMT (**Tables 1, 2, 3**) to ensure model validation of the model (Rehman and Zeb, 2023; Rehman and Prokop, 2023). Thereafter, the output of PLS-SEM indicates that all the values are lying in the acceptable range and confirms the validation of the model. Moreover, the variance inflation factor (VIF) procedure was applied to assess the multicollinearity among constructs (Rehman et al., 2023). The findings reveal that there are no issues of multicollinearity in the defined settings.

Table 2. Factors loading, Cronbach's alpha, Composite Reliability, AVE

Construct	Items	Factors Loading	Cronbach's alpha	Composite Reliability(rho-a)	Composite reliability (rho-c)	AVE
Barriers (BAR)	BAR1	0.836	0.895	0.906	0.918	0.617
	BAR2	0.791				
	BAR3	0.737				
	BAR4	0.755				
	BAR5	0.670				
	BAR6	0.782				
	BAR7	0.905				
Research & Development (R&D)	R&D1	0.704	0.888	0.898	0.913	0.601
	R&D2	0.785				
	R&D3	0.706				
	R&D4	0.789				
	R&D5	0.891				
	R&D6	0.741				
	R&D7	0.793				
Public Knowledge (PK)	PK1	0.830	0.642	0.655	0.847	0.735
	PK2	0.884				
Market Knowledge (MK)	MK1	0.722	0.821	0.821	0.882	0.653
	MK2	0.797				
	MK3	0.816				
	MK4	0.889				
Eco-Innovation (ECO)	ECO1	0.552	0.855	0.876	0.889	0.538
	ECO2	0.714				
	ECO3	0.701				
	ECO4	0.813				
	ECO5	0.832				
	ECO6	0.742				
	ECO7	0.746				
Environmental Policies (EP)	EP1	0.908	0.885	0.898	0.921	0.745
	EP2	0.798				
	EP3	0.922				
	EP4	0.817				
	PF1	0.790	0.734	0.735	0.850	0.653

Public Finance (PF)	PF2	0.809				
	PF3	0.825				

Table 3. Discriminant Validity

	Barriers	ECO-Innovation	Market Knowledge	Public Knowledge	R&D
Barriers	0.785				
ECO-Innovation	0.460	0.733			
Market Knowledge	0.550	0.549	0.808		
Public Knowledge	0.392	0.498	0.475	0.857	
R&D	0.522	0.550	0.509	0.503	0.775

Table 4. HTMT

	Barriers	ECO-Innovation	Market Knowledge	Public Knowledge	R&D
Barriers					
ECO-Innovation	0.405				
Market Knowledge	0.431	0.435			
Public Knowledge	0.311	0.453	0.437		
R&D	0.378	0.308	0.367	0.465	

4.2 Structural Model

In the PLS-SEM procedure, usually, the technique of structural model technique is applied to test the hypothesis developed in the theoretical settings. For the assessment of direct relationships, the technique of bootstrapping was applied to display the image of relationships among constructs. The findings indicate that barriers to innovation, market knowledge, public knowledge, and R&D have a significant positive relationship with eco-innovation between firms in Central European countries (**Table 4**). The results also show that innovation barriers have a significant positive relationship with the market knowledge, public knowledge, and R&D among firms in the Central European countries. Additionally, the study found that R&D has a mediating role between barriers to innovation and eco-innovation among firms in Central European countries (**Table 5**). The findings also show that public knowledge plays a mediating role between barriers to innovation and eco-innovation among firms in the central European countries. Furthermore, the results reveal that market knowledge plays a mediating role between barriers to innovation and eco-innovation among firms in Central European countries. Further, the study has noted that the values of Q-Square are non-zero, which clarifies that the path model predictive relevance exists in this study. (**Appendix, Figure A1**)

Table 5. Direct Effects

Relationship	β	Sample Mean	SD	t-value	P-value	Decision	R^2	F^2	VIF	Q^2
BAR → ECO	0.227	0.229	0.061	3.744	0.000	Supported		1.056	1.446	

MK → ECO	0.163	0.163	0.114	2.028	0.033	Supported	0.359	2.007	4.11	0.183
PK → ECO	0.165	0.165	0.081	2.047	0.041	Supported		2.015	2.85	
R&D → ECO	0.151	0.155	0.126	2.304	0.029	Supported		2.005	3.222	
BAR → MK	0.55	0.552	0.038	14.49	0.000	Supported	0.302	1.433	1.000	0.186
BAR → PK	0.392	0.395	0.048	8.195	0.000	Supported	0.153	2.181	1.026	0.106
BAR → R&D	0.522	0.524	0.041	12.60	0.000	Supported	0.272	2.374	1.005	0.158

Table 6. Indirect Effects

Relationship	β	Sample Mean	SD	t-value	CILL	CIUL	Decision
BAR→ R&D→ECO	0.079	0.081	0.067	1.981	0.047	0.218	Supported
BAR→ PK→ECO	0.065	0.065	0.032	2.020	0.001	0.129	Supported
BAR→ MK→ECO	0.090	0.09	0.063	2.116	0.033	0.213	Supported

Furthermore, to additionally enrich the knowledge area, the study evaluated environmental policies and public finance in the capacity of control variables. Surprisingly, the findings reveal that environmental policies and public finance have positive aspects (**Appendix, Figure A2**). Usually, in the PLS-SEM analysis procedure, the t-value is preferable to decide the acceptance and rejection of the hypothesis. According to the recommended procedure, if the t value is higher than 1.65 and both the lower confidence interval and the upper confidence interval are in the same direction for the indirect relationship, then the hypothesis can be accepted (Memon et al., 2018; Ramayah et al., 2018; Rehman, 2019). Therefore, the results in **Table 6** indicate that the t values are higher than the recommended threshold values, and both the lower confidence interval and the upper confidence interval are in a positive direction, so the hypothesis concerned can be accepted. Moreover, the study observed that with the addition of environmental policies and public finance, the relationship between the barriers to innovation, market knowledge, public knowledge, and R&D becomes insignificant with eco-innovation among firms in Central European countries. Therefore, based on the results, it can be inferred that environmental policies and public finance do not play a favourable role in the capacity of the control variables in the current theoretical settings. Furthermore, to evaluate endogeneity among constructs and assess model accuracy, the study applied the Gaussian Copula procedure in PLS-SEM to handle endogeneity issues of endogeneity (Becker et al., 2022; Shela et al., 2023). According to the Gaussian Copula approach, the study found that (GC (BAR → ECO) P=0.735; GC (MK → ECO) P = 0.134; GC (PK → ECO) P= 0.061; GC (R&D → ECO) P=0.317; GC (EP → ECO) P= 0.086; GC (PF → ECO) P= 0.0726) the P-values are insignificant in all cases and concluded that there are no issues of endogeneity between constructs.

Table 7. Evaluation of Control Variable

Relationship	St. Beta	Sample Mean	SD	P-Value	St. Beta	Sample Mean	SD	P-Value
	Model-I				Model-II			
BAR → ECO	0.227	0.229	0.061	0.000	0.017	0.015	0.089	0.848
MK → ECO	0.163	0.163	0.114	0.033	0.155	0.156	0.110	0.159
PK → ECO	0.165	0.165	0.081	0.041	0.145	0.145	0.079	0.067

R&D → ECO	0.151	0.155	0.126	0.029	0.109	0.110	0.120	0.364
BAR → MK	0.550	0.552	0.038	0.000	0.550	0.552	0.038	0.000
BAR → PK	0.392	0.395	0.048	0.000	0.392	0.395	0.048	0.000
BAR → R&D	0.522	0.524	0.041	0.000	0.522	0.524	0.041	0.000
EP → ECO					0.146	0.149	0.087	0.091
PF → ECO					0.159	0.162	0.091	0.080

5. Discussion

All our hypotheses were supported in this study. The first and most important hypothesis on the link between the innovation barriers and eco-innovation was approved, confirming the results of Hojnik et al. (2022). This result is also in line with the results of studies by Horbach et al. (2012) and Hrabynskyi et al. (2017). Therefore, we can say that firms analysed facing innovation barriers are triggered to create eco-innovations in Central Europe. We also approve a second hypothesis confirming another statement by Hojnik et al. (2022) - that innovation barriers encourage R&D. We found that innovation barriers trigger R&D activities to a more considerable extent than they boost eco-innovations. Moreover, as a result of additional analysis, we proved that R&D has a positive mediating role in the relationship between innovation barriers and eco-innovations. R&D served as a mediating factor between innovation barriers and eco-innovations in our study. The results of our analysis showed that R&D has a positive effect not only on a firm's conventional innovations in Central Europe, as mentioned by Klimova (2018) and Prokop et al. (2021), but also on eco-innovation activities. Therefore, we also confirm hypothesis number three, and consequently the results of Orlando et al. (2020) and Dimakopoulou et al. (2022), and in part, the results of Halásková and Bednář (2018) and Prokop and Stejskal (2019).

Next, we also confirm that, despite the presence of significant innovation barriers in Central European countries, e.g., lack of financial resources (Horbach, 2016; Hojnik and Ruzzier, 2016), innovation barriers still serve as motivation for attracting both types of external knowledge (public and market) to companies. In this regard, we see that the influence of barriers on market knowledge sourcing is more significant than the influence on the public one. These outcomes are essential for us because, according to Horbach et al. (2013), eco-innovations rely on external knowledge more heavily than other types of innovation do. The presence of incentives to obtain external knowledge is good news for firms' potential to eco-innovate. Here, we confirm a general statement of Radošević (2017), which states that CE countries are more dependent on external (foreign) knowledge and technology flows.

In turn, both market and public knowledge proved to be significant in triggering eco-innovations in Central Europe. The influence of these two types of knowledge on eco-innovations is of almost equal significance. This means that we don't see a clear distinction between public and market sourcing in this case, unlike in the case of the effect of innovation barriers on them. Such outcome partly corresponds to the outcomes of Cainelli et al. (2012), Sanchez-Henriquez and Pavez (2021), and Chaparro-Banegas et al. (2023), which confirm the impact of external knowledge on eco-innovation. Dividing into parts, the results for market knowledge sourcing match the conclusions of Sanchez-Henriquez and Pavez (2021). However, the outcome differs from another one by Chaparro-Banegas et al. (2023), Orlando et al. (2020), and Long and Liao (2021), where authors concluded that public R&D cooperation is more impactful on firm's eco-innovations, compared to the private one. Ociepa-Kubicka and Pachura (2017) also stated that eco-innovations depend more on public than private sources of financing. On the other hand, Jiménez-Parra et al. (2018) found the opposite trend in the impact of private and public R&D. With these results, to some extent, we disapprove of the statement of Sáez-Martínez et al. (2016), who found a negative relationship between cooperation with R&D institutions and eco-innovations and complement the results of Diaz-Garcia et al. (2015), who found positive impact only for conventional innovations. In summary, surprisingly, we can conclude that there is no distinctive difference between the influence of public and market sources. However, both proved to be significant for eco-innovations.

6. Conclusions

This study brings new knowledge on the influence of innovation barriers on the environmental behaviour of firms in Central Europe. Our results contribute to the current state of knowledge regarding eco-innovations in the territory of Central Europe, where similar types of analyses were rather exceptional. However, this type of analysis was necessary to be able to provide relevant information and recommendations to both firms and public policy makers (Chaparro-Banegas et al., 2023). Based on our findings, we therefore suggest several practical implications below.

For firms, we recommend implicating additional external knowledge from all possible sources in order to increase their eco-innovativeness. Both types of knowledge, public and market knowledge, proved to be beneficial to companies. It could be done by strengthening cooperation with other market players and government institutions (Sanchez-Henriquez and Pavez, 2021). In addition, we recommend attracting government grants, incentives, and subsidies that specifically aimed at implementing innovations that reduce the environmental impact and meet the objectives of the Sustainable Development Goals (Ullah et al., 2023). It can be done through applying for different governmental and EU environmental programmes (renovation, more efficient heating, lighting, water management systems, etc.). As governments are interested in this type of innovation, and it would help firms with financial resources, the lack of which is one of the main innovation barriers. We can also suggest more investment in eco-innovations, as Afshari et al. (2020) advised companies to implement eco-innovations to make production processes more efficient and to improve the supply chains.

Concerning policy implications, we recommend private companies to increase the investment in public research and development activities, which would lead to the creation of knowledge that helps to implement eco-innovations. Hojnik et al. (2022) made a similar recommendation for companies in Central Europe. We also advise to governments and policymakers to invest in research and development in case they have policies aimed at reducing environmental impacts. Investment in R&D and subsequent introduction of eco-innovations would benefit both governments and companies in smoothening the implementation of the new regulations, as well as in reducing the cost of production and potentially complying with stricter environmental policies. These recommendations align with the ones by Hojnik and Ruzzier (2016) and Orlando et al. (2020). In addition, Su et al. (2021) also recommended governments to give more power to local authorities in implementing eco-innovations to increase their efficiency.

Similarly to Hojnik et al. (2022), we suggest that governments incentivize eco-innovation activity by reducing some of the barriers to innovation. Despite the willingness to eco-innovate with the existence of barriers, policymakers have to stimulate more of such behaviour by lowering taxes and subsidizing the firms that eco-innovate. Hajdukiewicz and Pera (2023) suggest, based on their research, that the main direction of improvement for eco-innovation in catching-up economies includes an increase in the share of people employed in the R&D sector, patenting eco-innovations, and increasing energy efficiency in enterprises.

We reached a conclusion that despite the presence of significant innovation barriers in Central European countries (like lack of financial resources or skilled workforce), companies are still willing to implement eco-innovations. We supplemented the results of studies of previous researchers (Klimova, 2018; Prokop et al., 2021) for general innovation in Central European countries by adding the results for eco-innovations. We found that, except for eco-innovations, innovation barriers also motivate companies to implement R&D activities and public and market knowledge. However, we discovered that innovation barriers stimulate market knowledge to a greater extent than they stimulate public knowledge, as well as foster R&D activities more notably than they boost eco-innovations. R&D proved to be an important mediating factor between innovation barriers and eco-innovations. With respect to our control variables, the effect of environmental policies and public finance was not significant enough.

Our study is not without limitations. The potential main limitation of this research can be considered that our dataset is from the period 2012-2014. On the other hand, newer versions of the CIS questionnaire do not provide information on firms' eco-innovation and environmental behaviour, and thus we can also see the use of this questionnaire in other recent studies as well (Horbach, 2016; Prokop and Stejskal, 2019; Audretsch and Belitski, 2020). In addition, thanks to this questionnaire, we can provide the reader with a more comprehensive view of the behaviour of firms in Central Europe, and at the same time, we can inspire other researchers for follow-up research.

Based on this, we make several recommendations for future research. First, we recommend performing these analyses on more recent data. Second, future research could concentrate on the other factors that can influence the implementation of eco-innovations in companies in Central Europe, which we did not consider in our study (related, e.g., to innovation capacity, human capital), and data for which are not present in the Community Innovation Survey. Additionally, research can be conducted using data from other European countries or from countries in other growing regions of the world (e.g., Asia). Apart from that, we only used inputs listed as innovation barriers in the CIS 2014. The list of innovation obstacles in the survey is comprehensive enough; however, there are more existing innovation barriers.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix

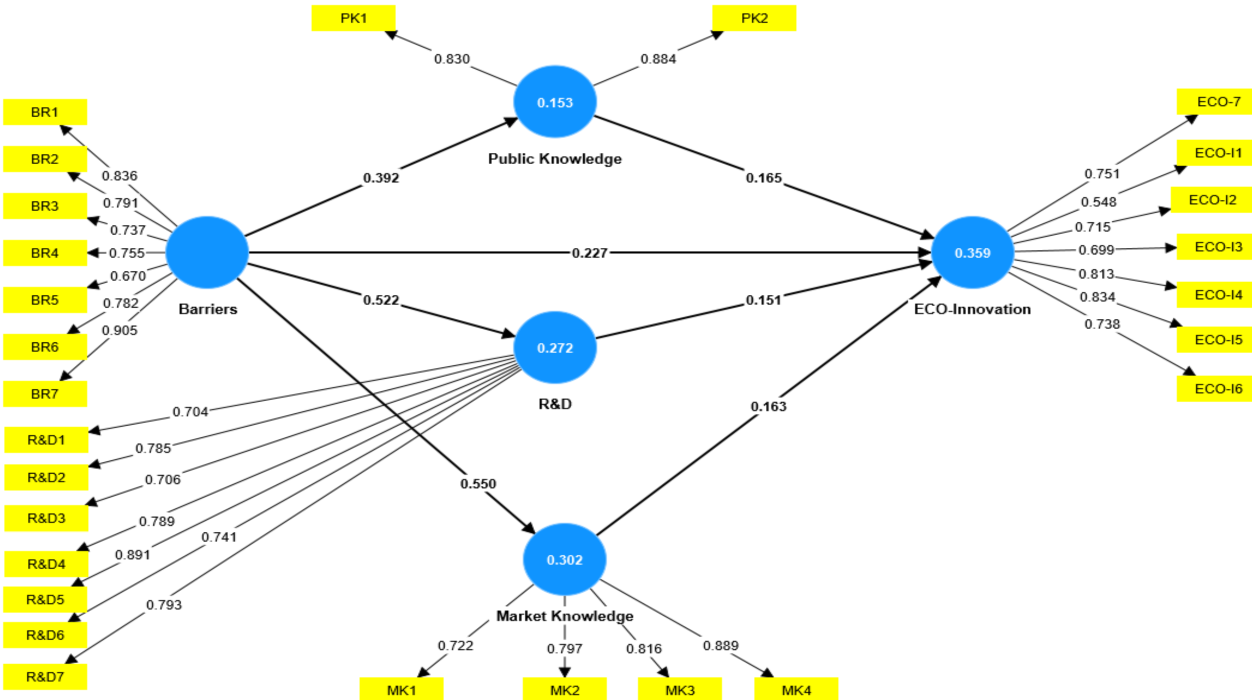

Figure A1. Relationships among main variables

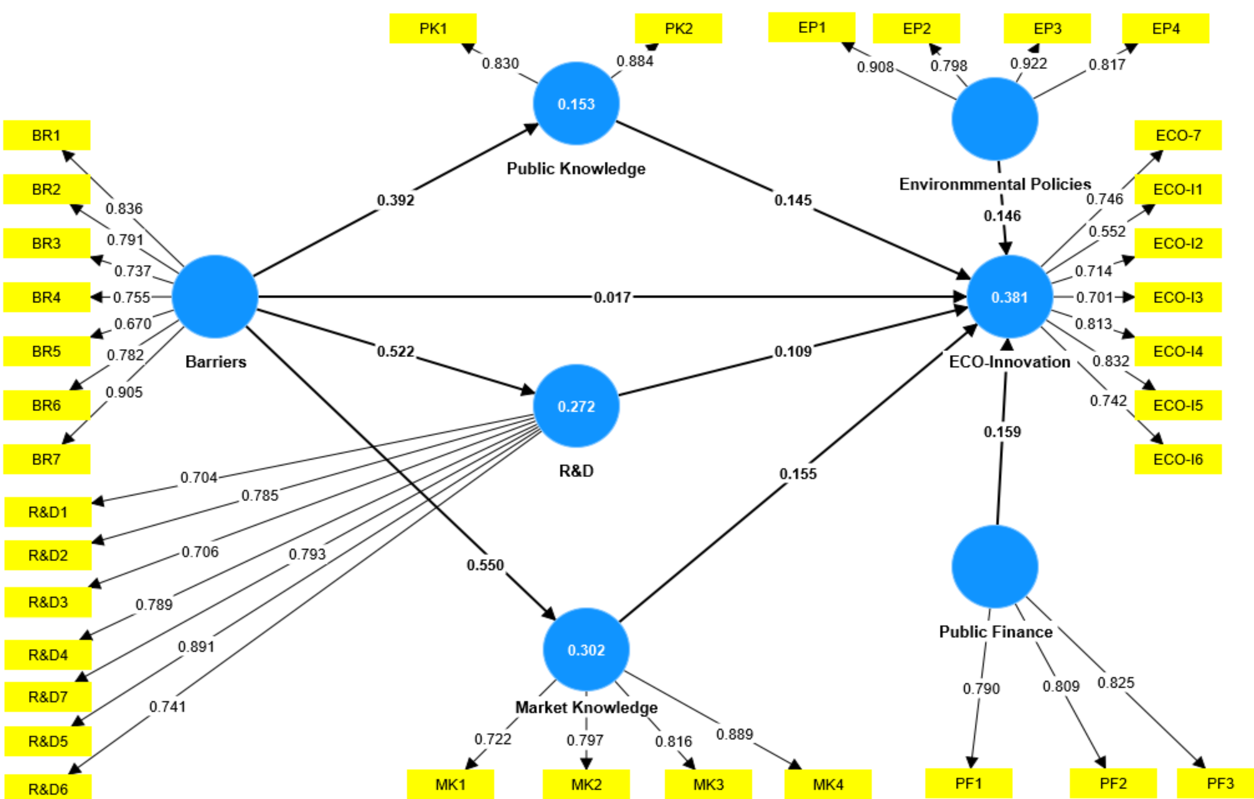

Figure A2. Relationships among main and control variables