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Empirical Paper

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Evaluating the impact of public financial support on innovation activities of European Union enterprises: Additionality approach

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Abstract: The study aims at estimating the effects of support for research and development and innovation from the European Union (EU) budget for boosting innovation in European enterprises, using input, output, and behavioral additionality approach. The study is based on microdata of the Community Innovation Survey 2012–2014, covering a sample of 98,809 enterprises from 14 EU countries. The direct and indirect relationships between the variables were studied using path analysis. For the whole sample, three additionality dimensions were confirmed; however, the result differs across EU member states. Multi-additionality of EU grants was confirmed only for Spain; in eight EU countries, input and behavioral additionality were proved, and in two, only behavioral additionality was found. This leads to the conclusion that the potential of EU support is not fully exploited, in particular in Central and Eastern European countries, and there is room for improvements with regard to policy design and implementation.

Keywords: additionality of public support, European Union, innovation, innovation policy, R&D grants
JEL Classification: C50; L2; O3

1 Introduction

Innovation is an important factor for tackling the major societal challenges such as climate change, scarce natural resources, or aging of society. To address these challenges, a holistic approach to innovation policy is required [Bengtsson and Edquist, 2022]. Therefore, it is important to study additionality effects of different public support instruments to design innovation policy mix tailored to the problems to be solved. In this study, we focus on research and development (R&D) grants offered to European firms from the European Union (EU) budget. The rationale for government intervention in the field of R&D and innovation (R&D&I) is

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to reduce market failures (e.g., information asymmetries and coordination failures) that impede enterprise innovation activity, minimize the negative effects of technology on society, coordinate interdisciplinary research, or reduce the costs and risks of creating innovations required for the development of economy-wide infrastructure [Atkinson and Ezell, 2012; Rothwell and Zegveld, 1982, pp. 9–10]. However, public involvement is appropriate only when the market cannot fulfil the country's strategic goals and intervention can help alleviate or minimize current problems [Edquist, 2011; Edquist and Zabala-Iturriagagoitia, 2020]. Well-designed innovation policy tools should provide some additionality impacts while not replacing, duplicating, or crowding out activities that firms can carry out on their own [Edquist, 2019]. Thus, the idea of additionality assumes that as a result of public funding supporting firms' R&D&I additional business R&D investment occurs, and new products or business processes will be introduced on the market. However, the results of empirical studies on this topic are mixed. A comprehensive review of 98 empirical studies published between 1960 and 2017 on the effectiveness of public support for R&D&I in the EU, China, and Taiwan confirmed that the impact can be positive or negative, depending on firm size, sectors, the source of the money (international, national, or regional), the type of the support scheme, and how the scheme fits with other elements of the innovation system [Petrin, 2018]. The most recent research on the additionality of R&D has also demonstrated that the impact differs between industries, countries, and additionality types. A study on R&D subsidies for patenting activity of enterprises in Norway validated output additionality, demonstrating that its quantity is strongly dependent on firm characteristics [Bye et al., 2019]. By contrast, Nilsen et al. [2020] showed in their research on Norway that the output additionality of this support supplied to incumbent enterprises performing regular R&D activity was statistically insignificant, which mattered for R&D starters. Grabowski and Staszewska-Bystrova [2020] discovered that the influence of public support on innovation varies between EU member states and sectors. Some studies also showed that the approach employed in modeling the influence of policy measures on innovation matters for the results obtained as no model is flawless [e.g., Annicchiarico et al., 2020; Benedetti et al., 2020]. The examples of fragmented and mixed results on additionality given above indicate that further empirical research is needed to compare the additionality effects of financial public support for innovation at the business level. This work attempts to address this research gap by providing new evidence on all categories of additionality (input, output, and behavioral) in 14 EU countries.

There are three dimensions of the impact of the public support to innovation analyzed in the study: (1) change in input for innovation (measured by additional money invested in R&D or in a purchase of a new machinery), (2) increase in the innovation output (measured by the proportion of turnover coming from new and significantly improved products), and (3) behavioral change leading to innovation (measured by enterprises' cooperation in innovation activity and additional training of their employees that would not appear without public support). These three dimensions are defined in the literature as additionality effects of public support. They are analyzed in this study in order to find out whether and how the R&D grants received by European enterprises from the EU budget impact their innovation activity.

The total initial sample of N = 98,809 covered 15 countries: Bulgaria (BG), Cyprus (CY), the Czech Republic (CZ), Germany (DE), Estonia (EE), Greece (EL), Spain (ES), Croatia (HR), Hungary (HU), Lithuania (LT), Latvia (LV), Norway (NO), Portugal (PT), Romania (RO), and Slovakia (SK). This comparative analysis was carried out based on firm-level data derived from the Community Innovation Survey (CIS) conducted for the period of 2012–2014.

The article is divided into four sections. Following the Introduction, the concept of additionality of public support to R&D&I is explained on the basis of the relevant literature. Then, distinct additionality aspects are explained, and the results of prior empirical research on this topic are reviewed to generate hypotheses on potential additionality effects of R&D&I support to business innovation activity coming from the EU budget.

Following the literature review, there is a description of the firm sample and a summary of the methodology applied in this study. The path analysis is carried out independently for each sample of European firms. Following that, hypotheses are tested, and empirical findings are presented and discussed.

The final section of the study draws conclusions, which provide new insight into the evaluation of the success of EU support to R&D&I as well as policy implications.

2 Literature review and research hypotheses

Schot and Steinmueller [2018] distinguished three approaches to science, technology, and innovation policy: the first is based on neoclassical assumptions about the linear relationship between R&D&I, the second is based on the introduction of the innovation system concept in innovation policy design, and the third is based on the need to address social and environmental challenges.

Nonetheless, all approaches to innovation policy recognize that it is a component of economic policy aimed at stimulating the development of new products, processes, or services, as well as their implementation and widespread adoption [Edler et al., 2013; Weresa, 2017; Borrás and Edquist, 2019; Geels, 2020]. Innovation is required to increase enterprise efficiency and improve economic growth for the benefit of society as a whole [Crépon et al., 1998; Van Leeuwen and Klomp, 2006].

The system of support for innovative activities includes a number of instruments, such as R&D grants, innovation subsidies, tax credits, public procurement rules, and support measures for intellectual property exploitation. A two-dimensional taxonomy of innovation policy instruments identifies two major categories: those geared for supply-side interventions and those designed for demand-side interventions [Edler et al., 2013, p. 13]. Becker [2015] mapped public innovation support across Europe, highlighting disparities between EU countries with regard to instruments used as well as political levels of support [Becker, 2015].

Therefore, the efficiency of public support for innovation may be investigated while taking into account a variety of policy support instruments as well as the different levels at which the support is provided. This article considers two major features of the influence of public financial support to the innovation activities of EU enterprises: the diversity of impact areas (type of additionality) and the diversity of impact levels (direct and indirect impact).

We examine the financial assistance received by European businesses from the EU level, taking into account three major areas of impact (additionalities) identified in the economic literature: input, output, and behavioral additionality.

Input additionality occurs when public funds transferred to enterprises in a form of a subsidy or grant result in additional corporate R&D expenditures [Georghiou, 2004]. However, it does not happen automatically. Government R&D funding may also crowd out private R&D spending. This suggests that private R&D spending may be reduced as a result of the public subsidy or grant [Edquist et al., 2004]. Different scholars have studied the issue of input additionality [e.g., David et al., 2000; Clausen et al., 2007; Marzucchi and Montresor, 2012; Christensen et al., 2018; Czarnitzki, and Hussinger, 2018], but the results vary for different countries and also depend on the source and type of support, as well as industry.

Hussinger [2003] investigated German corporations and found no evidence of crowding out impacts of governmental R&D subsidies on firms' R&D expenditures. On the contrary, the input additionality was validated. Czarnitzki and Hussinger [2018] obtained similar results by using data from the Mannheim Innovation Panel and conducting a treatment analysis to assess for crowding out effects of public R&D granted by the German Federal Government to over 500 grantees from 1992 to 2000. The impacts of full and partial crowding out, as well as acceleration, were investigated. The key finding was that supported enterprises expanded their volume of R&D spending by using their own resources and raising additional private capital.

Gonzalez et al. [2005] conducted a large-scale study in which they examined a panel of over 2,000 Spanish enterprises and concluded that public subsidies stimulate R&D expenditures, but they also demonstrated that innovation projects could have been continued without public support. Another study on Spanish enterprises by Afcha and Lucena [2021] used data from the Spanish Business Strategy Survey also confirmed input additionality showing that public support induced additional private R&D effort.

When it comes to the source of public assistance, Grabowski et al. [2013] conducted an interesting comparative study on manufacturing businesses from Turkey and Poland estimated an econometric model developed by Crépon, Duguet and Mairesse (so called CDM model) for the CIS micro-data for the period 2008–2010. Input additionality was confirmed at the national and EU levels for both countries. Grabowski and Staszewska-Bystrova [2020] discovered industry and country disparities in the impact of R&D&I funding granted to European small and medium sized enterprises (SMEs) from the EU and national budgets using CIS 2014 data in a multivariate, multi-stage econometric model. The input additionality of EU public support for R&D&I was confirmed for a group of "new" EU member states, while output additionality was revealed in the "old" EU countries and Norway. In addition, the additionality effects differed between the manufacturing and service sectors. The authors also demonstrated that simultaneous assistance for R&D&I from both the EU and state budgets resulted in a higher beneficial impact.

In turn, Czarnitzki and Lopes-Bento [2014] found that for German enterprises, national and European policy instruments complement each other. Czarnitzki and Delanote [2015] also studied small- and medium-size German enterprises that received grants from the EU. The full crowding out effect was not confirmed for all studied firms, and the input additionality was the strongest in high-tech young enterprises. Alecke et al. [2012] analyzed the impact of public subsidies on firms in East Germany and confirmed both input and output additionality.

Some research have found that public financial support to innovative activities has a crowding out impact. It was discovered for instance for big Spanish firms [Serrano-Velarde, 2008]. The crowding out effects of public assistance were also confirmed in French enterprises that received public assistance for their innovation activity between 1993 and 2009 [Marino et al., 2016]. Wallsten [2000] investigated a sample of American businesses and demonstrated the crowding out impacts of publicly financed R&D funds. However, some favorable benefits of the investigated programs were discovered. Additional R&D funding supported the continuation of higher levels of R&D spending, which would not have been possible in the long run.

The review of empirical research on input additionality conducted above shows that the results regarding input additionality are mixed.
Based on the literature review, we formulate the following *input additionality hypothesis*:

H1: Public financial support from the European Union programs stimulates directly firms' R&D budget.

Another aspect of public support for innovation is output additionality, which means that grants or subsidies have a direct positive impact on the degree of firm's innovation [OECD, 2006; Edler et al., 2013]. Such direct effects are typically measured by new products, new processes, patents, and publications, but some indirect output effects of publicly supported projects, such as improvements in financial standing and performance caused by the introduction of new products or processes, can also be observed [Georghiou, 2002].

Previous studies on this topic yielded a variety of results, ranging from significant innovation output increases caused by public R&D subsidies to lack of evidence on output additionality or even confirming crowding out effects (decreased innovative output) resulting from public R&D grants. The output additionality was discovered in German firms, but not in innovative young enterprises [Schneider and Veugelers, 2010]. Roper and Hewitt-Dundas [2016] examined the influence of state subsidies on the innovative activity of 3,254 Irish manufacturing facilities from 1991 to 2011, confirming output additionality. Similar results were obtained for Hungarian enterprises [Halpern, 2010]. The positive influence of government subsidies on the number of new innovations introduced has also been confirmed for Spanish firms [Albors-Gorrigos and Barrera, 2011].

Radas et al. [2015] investigated the effects of two innovation policy instruments in Croatia, namely, direct R&D subsidies and tax breaks for SMEs. Based on a sample of 700 Croatian enterprises that received public subsidies or tax breaks between 2005 and 2010, they discovered that both policy instruments boosted sales achieved by the firms studied.

Bronzini and Piselli [2016] validated the output additionality of Italian companies' patenting activity by demonstrating that government subsidies boosted the likelihood of applying for patents in the case of small enterprises. A study of German enterprises' patenting activity revealed that publicly funded R&D had a beneficial impact on patents. Furthermore, the positive benefit of additional R&D caused by government funding has been demonstrated [Czarnitzki and Hussinger, 2018].

The effectiveness of R&D grants depends on the source of funds. According to the findings of a study conducted on Austrian enterprises between 1998 and 2000, support from national public sources boosted the share of sales from innovative items, while EU support was shown to be insignificant [Garcia and Mohnen, 2010]. Weresa and Lewandowska [2014] obtained similar results for public support from the EU budget received by enterprises in Poland. Structural equation modeling (SEM) of CIS 2010 data revealed that EU-funded R&D&I initiatives had no direct effects on Polish companies (i.e., output additionality measured as a share of sales of innovative items in total sales did not increased due to the EU grants). Grabowski et al. [2013] studied the effects of public support in Poland and Turkey and also found that the source of grants matters. Output additionality occurred exclusively for the national government and EU support, but not for local government support.

In turn, Becker [2015] discovered a negative influence of public innovation assistance on turnover changes, but he also observed some favorable benefits on labor productivity.

Freitas et al. [2017] demonstrated a boundary perspective on output additionality. The research looked at businesses in three European countries: France, Italy, and Norway. The authors demonstrated both input and output additionality using data from three waves of the CIS (2002–2004, 2004–2006, and 2006–2008), as well as confirming that the higher the level of technology, the stronger the effects emerged. However, the results varied depending on the country studied. There are significant disparities in the results when it comes to the source of money.

Radicic and Pugh [2017], based on a sample of small- and medium-sized companies from 28 European countries, claimed no evidence of output additionality from national programs and crowding out impact from EU programs, which may be mitigated by combining them with national programs. Similarly, neither input nor output effects were discovered for small- and medium-sized businesses from six Western Balkan nations [Orlic et al., 2019].

As the results of empirical research are again inconclusive, we will test the following research hypothesis about *output additionality*:

H2: Public financial support from the EU programs causes a direct improvement of firms' innovation performance.

The third dimension of public support studied in this work is behavioral additionality as programs supporting R&D&I offered at the European level are frequently designed to facilitate the establishment or continued development of collaboration in innovation activity and the formation of pan-European networks [Buisseret et al., 1995]. Behavioral additionality also refers to the effects of policy interventions such as new competencies gained by firm personnel, changes in working procedures, building new networks, and entering new business areas [Neicu et al., 2016, p. 101]. As the variety of behavioral effects may occur as a result of public support to R&D&I, it inspired many scholars to distinguish sub-categories of this phenomenon.

Roper and Hewitt-Dundas [2016, pp. 12–17] distinguished three types of behavioral additionality: congenital additionality, which is related to employee education and experience; inter-organizational additionality, which is related to new innovation linkages created by public support schemes; and experiential additionality, which is related to changes in firm processes and routines induced by public support for innovation, and they tested them empirically. The study of these three behavioral effects of public subsidies, conducted over a 20-year period for a large sample of 3,254 Irish manufacturing firms revealed that prior public support for new product development activity enhanced technical skills, confirming congenital additionality. Prior public subsidies were also significant for the positive benefits of collaboration in innovative activity, resulting in inter-organizational additionality. However, no evidence of experiential additionality was found [Roper and Hewitt-Dundas, 2016].

All in all, behavioral additionality is more difficult to trace than input or output additionality as it covers many different elements characterizing firm's innovation capabilities and is not easy to measure with quantitative indicators. Apart from cooperation and training, the behavioral additionality includes learning externalities (sometimes distinguished as project additionality) or some scale effects, such as undertaking of more ambitious projects [Weresa et al., 2018, p. 20].

Empirical results of research on behavioral additionality are inconclusive. Some scholars—for example, Roper and Hewitt-Dundas [2016] already referred to the previous aspect—proved the significance of public subsidies for innovation for behavioral changes related to education and cooperation, not fully confirming experiential additionality connected with changes of processes and routines. Furthermore, they confirmed "the legacy effects" of public support taking into account subsidies received by firms in the previous period.

Many studies concentrated on the outcomes of public R&D&I assistance for changes in companies' relationships with the research sector, suppliers, clients, and competitors. The idea of collaboration additionality of public support was validated for technologically specialized enterprises in the Austrian transportation sector with relatively moderate R&D intensity [Wanzenböck et al., 2013]. The scope of collaboration in innovation, as well as the scale of innovative projects, underwent behavioral change in these sponsored firms.

Weresa and Lewandowska [2014] demonstrated, using data from the CIS 2010 for Poland, that both domestic public assistance and EU-funded projects resulted in behavioral additionality, as evaluated by collaboration with institutional partners. Lewandowska and Kowalski [2015] demonstrated the behavioral additionality of EU financial support for Poland, but only for major firms grouped in clusters and cooperating with partners from the same clusters, not with partners from outside. Another study on Poland based on micro-data from 2010 indicated no behavioral additionality [Szczygielski et al., 2017], leading to the conclusion that EU grants for human capital development were ineffective in encouraging innovation in Poland.

In turn, the evidence for behavioral additionality in Asian countries is equivocal. For example, public R&D&I support schemes enabled South Korean biotechnology firms evaluated by Kang and Park [2012] to collaborate more actively in innovation activity with their suppliers and clients. Another study on biotechnology Korean corporations verified behavioral additionality, finding that firms backed by public R&D subsidies engaged in more strategic alliances than non-subsidized firms [Shin et al., 2019].

Behavioral additionality was also investigated for individual R&D programs and again results varied depending on the program type and country studied. A network study was conducted on a new program in the United States supported by the Alfred P. Sloan Foundation, which was aimed at incubating a new scientific subject "Microbiology of the Built Environment." The results revealed an increased density and networks among researchers, as well as a higher intensity of collaboration within this research community, thus confirming behavioral additionality [Hicks et al., 2019]. Another program-level study obtained opposite results. The ineffectiveness of Turkey's Priority Areas R&D Grant Program in terms of output, input, and behavioral additionalities was shown, and a stronger prioritization and coordination of national macro-, meso-, and micro-level policies were advised [Gürbüz and Erdil, 2020].

As existing empirical studies show ambiguous results regarding the impact of public innovation support on behavioral change in different countries, the third hypothesis concerning *behavioral additionality* is formulated:

H3: Public financial support from the EU programs intensifies firms' activity in cooperation with external partners and personnel training.

The literature confirms that the public financial support can enhance innovation performance both directly and also in an indirect manner. In order to test this effect, we first suppose the direct connection between knowledge acquisition and innovation performance, as well as cooperation and training and innovation performance and test a mediating role of both knowledge acquisition and cooperation and training.

Wubben et al. [2015] presented some intriguing findings regarding the effects of receiving knowledge from outside sources. According to the authors, knowledge exploration techniques have long-term consequences and produce radical discoveries, whereas knowledge exploitation tactics provide incremental innovations. Based on data from the Danish CIS, the authors claim that companies that use licenses develop incremental innovations, whereas radical innovations emerge as a result of enterprise acquisitions and mergers. The role of knowledge-sourcing activities for effectiveness of R&D subsidies was also researched by Afcha and Lucena [2021] for a sample of 1,178 manufacturing firms from Spain. The authors provided evidence that R&D subsidies for external knowledge drive firms innovation.

Van Beers and Zand [2014] investigated 12,811 innovative firms that took part in the Danish version of the CIS, as well as the R&D and Information and Communication Technology Surveys, between 1994 and 2006. They demonstrated, using tobit analysis for a panel of businesses, that diversifying collaboration partners in innovations has a synergistic impact for the introduction and commercialization of innovations. Simultaneously, geographical diversification of collaboration partners promotes adaptation of innovations to market requirements such as technical standards, market restrictions, or buyer preferences.

Based on these results, supposing the positive link between the knowledge acquisition as well as the positive influence of cooperation on the innovation performance of enterprises, we post the last hypothesis:

H4: Public financial support from the EU programs intensifies firms' innovation performance indirectly via the knowledge acquisition (H4a), and indirectly, through cooperation and personnel training (H4b).

All hypotheses gathered in the theoretical model are presented in Figure 1.

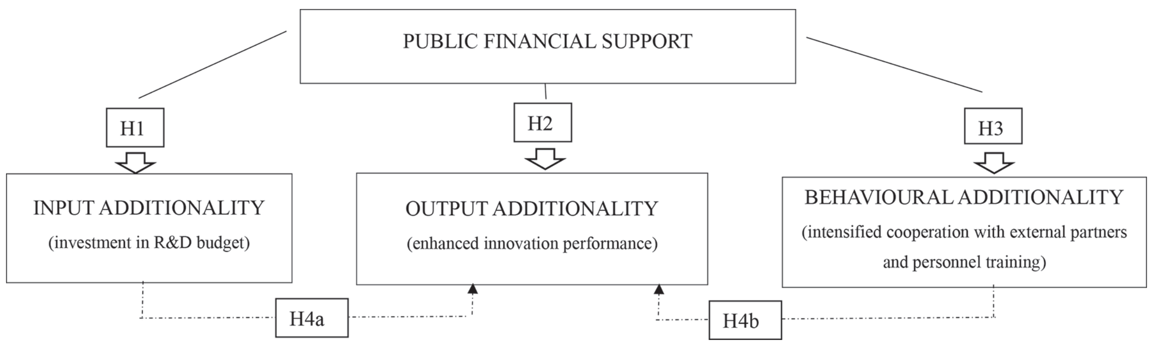

Figure 1. Theoretical model of the impact of public financial support on different activities of treated enterprise.
Source: Own elaboration.

While taking into account the three dimensions of the influence of innovation policy mentioned earlier (input, output, and behavioral), we can determine both the strength of impact on each of the three dimensions and the degree of complexity of impact. The effect of public financial support for innovative activities may take the following forms [Marzucchi and Montresor, 2012]:

1. *Multidimensional (systemic) support*: This is the case in which support takes place in the case of R&D expenditure (i.e., input), outcomes, and the behavior of the supported entity.
2. *Bi-dimensional support*: It is a situation in which the additional effect occurs in two of three dimensions.
3. *Mono-dimensional support*: This is the case in which the additional effect can be observed in only one dimension.
4. *Partial crowding out effect*: This is a situation in which we deal with the effect of crowding in one or two dimensions with a positive effect in the case of others.
5. *Total crowding out effect*: A situation in which there is a displacement effect for all three dimensions.

3 Research methodology

3.1 Context of the research

The quantitative analysis is based on anonymous firm-level micro-data from the CIS, covering years 2012–2014[1] from selected EU member states.

1 CIS micro data obtained based on the "*Contract on the use of Community Innovation Survey (CIS) micro data for research purposes 148/2016-CIS*" signed with European Commission Eurostat, Unit B1 – Quality, methodology and research.

The CIS is a survey on innovation activity of enterprises covering EU member states and candidate countries, Iceland and Norway, based on a common survey questionnaire and methodology, with reference to the Oslo Manual, ed. 2005. The CIS is designed to obtain information on firms' innovation activities, and it also contains data on the introduction of organizational and marketing innovations. The target population are small, medium, and large enterprises from NACE (Nomenclature statistique des Activités économiques dans la Communauté Européenne) sections A to N.

Research for CIS purposes is carried out by companies quoted in the official registers of enterprises kept by state statistical offices or other organizations recognized for this purpose by state authorities in the countries that provide data for CIS purposes. Surveys may be conducted on the total population of businesses, on randomly chosen samples, or using a combination of the two methods [CIS, 2008]. Stratification of the studied set is performed in accordance with the following factors: type of conducted activity (according to NACE Rev.2, indicating the nature of the activity), size of the employment (from 10 to 49 employees; from 50 to 249 and more people), and regional location.

National innovation research institutes are free to choose a sample of enterprises to be surveyed. The principle of pursuing the most accurate outcome without distorting the true picture of the issue serves as the foundation for research on trials.

Data for this research were obtained based on the individual research proposal submitted to Eurostat. It has to be remembered, however, that although the CIS questionnaire covers all 28 member states and candidate countries, not all of them revealed data for the research purposes on the micro-level, which is why the full coverage of all EU countries cannot be expected. Also, the release of the subsequent CIS waves for research purposes has a strong delay compared to the releases of aggregated CIS data.

3.2 Data collection and sample characteristics

The total sample of $N = 98{,}809$ covered 15 countries: Bulgaria (BG), Cyprus (CY), the Czech Republic (CZ), Germany (DE), Estonia (EE), Greece (EL), Spain (ES), Croatia (HR), Hungary (HU), Lithuania (LT), Latvia (LV), Norway (NO), Portugal (PT), Romania (RO), and Slovakia (SK). (See Table 1. for details.) The share of EU new member states (mostly CEE countries) amounted to 47.8% of the initial sample.

Table 1. Initial sample description

Country	Sample	Sample split
BG	14,255	14.4
CY	1,346	1.4
CZ	5,198	5.3
DE	6,282	6.4
EE	1,760	1.8
EL	2,507	2.5
ES	30,333	30.7
HR	3,265	3.3
HU	6,817	6.9
LT	2,421	2.5
LV	1,501	1.5
NO	5,045	5.1
PT	7,083	7.2
RO	8,206	8.3
SK	2,790	2.8
Total	98,809	100.0

BG, Bulgaria; CY, Cyprus; CZ, Czech Republic; DE, Germany; EE, Estonia; EL, Greece; ES, Spain; HR, Croatia; HU, Hungary; LT, Lithuania; LV, Latvia; NO, Norway; PT, Portugal; RO, Romania; SK, Slovakia; CIS, Community Innovation Survey.

Source: Own calculations based on micro-data from CIS 2012–2014.

We decided not to exclude any of the sections (NACE A–N) as our goal was to depict the whole economy and try not to bias the results. It should be noted, however, that not all firms in the sample answered all questions. The details of the split of the initial sample that has been obtained from Eurostat covering the multi-country samples micro-data of the enterprises are presented in Table 1.

3.3 Operationalization and measurement of variables

As we carry out our research based on the data from the standardized questionnaire, this determined the selection and operationalization of our variables.

In order to obtain the models that are comparable, we decided to use only binary variables in case of all variables: knowledge acquisition, cooperation and training, and public financial support. Due to the large differences between the values of the variable "innovation performance" and the need to analyze the percentage changes in its size, for this variable, we introduced a log of fraction (from 0 to 100) of turnover from innovative products introduced in 2012–2014 in the total turnover in 2014.

The details on the operationalization and measurement of variables are presented in Table 2.

Table 2. Variable operationalization

Variable	Description and construction of variables	Abbr. from CIS 2014
PubSuppEU	Variable—"Financial support from European Union"	
"1" if the firm received public financial support for innovation activity from EU; 0" otherwise.		FUNEU
InnoPerf	Variable—"Innovation performance of supported enterprise"	
Log of fraction (from 0 to 100) of turnover from innovative products introduced in 2012–2014 in total turnover in 2014		TURNMA + TURNIN
KnowAcq	Variable—"Knowledge acquisition as the proxy for R&D budget"	
"1" if the firm declared acquisition of machinery, equipment, software and buildings to be used for new or significantly improved products, processes or acquisition of existing knowledge from other enterprises or organizations (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; "0" otherwise		RMAC ROEK
InnoCoopTr	Variable—"Innovation cooperation and personnel training"	
"1" if the firm declared cooperation with local suppliers; customers; competitors; consultants; universities, research institutes, or cooperation with EU suppliers; customers; competitors; consultants; universities, research institutes, or cooperation with non-EU (China, India, the United States, other countries) suppliers; customers; competitors; consultants; universities, research institutes, or conducted internal or external training for its personnel for the development and/or introduction of new products and processes; "0" otherwise		Co11-Co75. RTR

CIS, Community Innovation Survey; R&D, research and development.

Source: Own compilation based on questionnaire CIS 2012–2014.

3.4 Methods applied

Multiple regression models are most typically used to examine the causal linkages between a certain set of characteristics and the examined phenomenon. However, these models have substantial limitations, leaving a number of causality analysis-related questions unsolved. First, the interpretation of the link between the explained variable and the predictor variables included in the model is restricted to the concept of covariance. Moreover, the structure of interactions between variables in regression models is oversimplified; it is assumed that predictor variables influence the variable explained simply directly.

In reality, the situation is significantly more complex. In a particular analysis, the predictive factors analyzed influence the dependent variable both directly and indirectly via other predictor variables. In this study, the relationship between the research variables was tested with the use of the path analysis [Wright, 1921, 1934], which can be viewed as similar to SEM in which only single indicators are employed for each of the variables in the causal model and is absent from the aforementioned limitations. The name “Path” refers to the analysis of the paths taken by the dependent variable as it relates to the predictor variables. In path models, causal links between variables are presumptively established and then verified. Path analysis is acknowledged as a statistical technique but also as an approach toward building theory in social sciences [Konarski, 2009]. It guides exploratory and confirmatory research in a manner combining self-insight and modeling skills with theory. It often suggests novel hypotheses that were not considered [Kline, 2011].

Path analysis enables simplifying the proposed theoretical model by eliminating the relationships between the variables for which the causal relationship effect is close to zero. Path analysis examines strength of the linear direct and indirect relationship between a dependent variable and two or more independent variables. The strength of the overall influence of a given *i*-th variable (independent or intermediary) on the *j*-th variable is determined by the values of the correlation coefficients r’ij reproduced on the basis of the path coefficients.

The values of the path coefficients are estimated on the basis of the so-called fundamental equations of path analysis, which has the following form:

$$r_{ij} = \sum_{q} p_{iq} r_{iq}$$

where r_{ij} is the correlation coefficient between the *i*-th and *j*-th variables, *p* is the path coefficient, and *q* runs through all the variables, the paths of which lead directly or indirectly from the *j*-th to the *i*-th variable.

The following assumptions about the model are made [Gaul and Machowski, 1987]:

(1) The relationships between the variables included in the model are causal, linear, and additive.
   a) Causal: For each pair of variables Z_i, Z_j, there is $Z_i \geq Z_j$ or $Z_j \geq Z_i$, and if $Z_i \geq Z_j$ and $Z_j \geq Z_k$, then $Z_i \geq Z_k$, where the relation $Z_i \geq Z_j$ means that Z_i may have a causal influence on Z_j, but Z_j cannot influence Z_i at the same time.
   b) Linear: If $Z_1, Z_2, \ldots, Z_i$ affect Z_j, then $Z_j = p_{j1}Z_1 + p_{j2}Z_2 + \ldots + p_{ji}Z_i + E_j$
   c) Additive: If, then pji = 0
(2) Residual variables *E* in the model are not correlated with each other and are not correlated with the variables preceding them in the model (Z_j).
(3) If for any pair of variables Z_i, Z_j, $Z_k \geq Z_k$ and $Z_k \geq Z_j$, then the variable Z_k is included in the model. The correlation of exogenous variables is treated as “data” not due to a common cause and beyond analysis.

It should be emphasized that the considered model creates a recursive system in which there are no feedback pressures, where individual variables could interact with themselves.

Solving a model’s system of equations is the same as solving its successive equations using the least squares method.

The formula for our model is as follows:

$KnowAcq = \beta_{10} + \beta_1 PubSuppEU + \xi_{KnwAcq}$

$InnoCoopTr = \beta_{20} + \beta_1 PubSuppEU + \xi_{InnoCoopTr}$

$InnoPerf = \beta_{30} + \beta_1 KnowAcq + \beta_2 PubSuppEU + \beta_3 InnoCoopTr + \xi_{InnoPerf}$

where

PubSuppEU is the public financial support from EU, KnowAcq is the knowledge acquisition, InnoCoopTr is the innovation cooperation and training, InnoPerf is the innovation performance, and β is the beta coefficient assessing the dependence of the *i*-th variable on the *j*-th variable, eliminating the influence of the *k*-th variable.

We calculate random factors (representing variables not included in the analysis) influencing the volatility of the variables included in the model on the basis of the following formula:

$$\xi_i = \sqrt{1 - R^2_{i.1,\ldots,l}}$$

where
$R^2_{i.1,\ldots,l}$ is the multiple determination coefficient defining the total effect of influencing the *i*-th variable of all variables included in the model (except for random factors).

We also introduced the bootstrapping—a method for assigning measures of accuracy to sample estimates [Efron, 1979], followed by correction bootstrap for goodness-of-fit measures [Bollen-Stine, 1992].

4 Results

The statistical approach to testing the hypothesis employed generalized least squares (GLS), with the module AMOS 23, program PS IMAGO. The initial model with assumed relations proved to be poorly fitted to the data (X^2 = 3823.065, df = 1 $p < 0.001$, X^2/df = 3823.065, CFI (Comparative Fit Index) = 0.259, RMSEA (Root Mean Square Error of Approximation) = 0.447).

Modification indexes suggest that the model should include the relationship between endogenous variables, while taking into account both the causal relationship KnowAcq on InnoCoopTr and InnoCoopTr on KnowAcq gives an improvement in fitting the modified model to the data. The relation KnowAcq to InnoCoopTr gives more improvement (0.497) than the relation InnoCoopTr on KnowAcq (0.342), although the difference between these results is not significant. A model with the relation InnoCoopTr to KnowAcq is further estimated for individual countries.

As the number of distinct sample moments are equal to the number of distinct parameters to be estimated, the model is saturated, and the quality of fitted model to the data is untestable. The model was bootstrapped (10,000 repeating), which additionally supported the obtained results. Analysis of standardized estimates for path depending shows that for group of units being a part of capital group, all paths are statistically significant at least at the level of $p < 0.05$.

Table 3 presents the estimated regression coefficients of these relationships that occur in the assumed model (estimate), as well as their values brought to comparability (standardized), standard errors of estimation (SE), and the level of critical significance (*p*-value) for the estimation (*** means significance below 0.001) for the total population of enterprises from 14 EU countries (we had to exclude Germany as the data were incomplete).

Results for the whole sample of 14 EU member shows that public financial support from EU budget (PublSuppEU) is conductive to the knowledge and machinery acquisition (KnowAcq) (H1) (standardized estimate of 0.203), innovation cooperation and training (InnoCoopTr) (H3) (standardized estimate of 0.063), and innovation performance (InnoPerf) (H2) (standardized estimate of 0.046).

We also revealed (what was not hypothesized) that cooperation in innovation and training (InnoCoopTr) has a positive significant influence on innovation performance (InnoPerf) (standardized estimate of 0.037) as well as on knowledge and machinery acquisition (KnowAcq) (standardized estimate of 0.430).

Based on the results for the whole sample from 14 European countries, we did prove the indirect effect of public support on performance through cooperation and training (H4).

Table 3. Results of path analysis for the whole sample of enterprises from 14 EU member states

Variable	Impact direction	Variable	H	Estimate	S.E.	*P*	Standardized
KnowAcq	<---	PublSuppEU	H1	0.417	0.015	***	0.203
InnoPerf	<---	PublSuppEU	H2	0.066	0.012	***	0.046
InnoCoopTr	<---	PublSuppEU	H3	0.107	0.011	***	0.063
InnoPerf	<---	KnowAcq		0.030	0.022	0.175	0.010
InnoPerf	<---	InnoCoopTr		0.065	0.014	***	0.037
KnowAcq	<---	InnoCoopTr		0.357	0.005	***	0.430

EU. European Union.

Source: Own elaboration based on results of path analysis.

***$p < 0.001$; **$p < 0.002$; *$p < 0.05$.

For the whole sample, the direct (unmediated) effect of InnoCoopTr on InnoPerf is 0.107. The indirect (mediated) effect of InnoCoopTr on InnoPerf is 0.149. This is in addition to any direct (unmediated) effect that InnoCoopTr may have on InnoPerf. The total (direct and indirect) effect of InnoCoopTr on InnoPerf is 0.256. That is, due to both direct (unmediated) and indirect (mediated) effects of InnoCoopTr on InnoPerf, when InnoCoopTr goes up by 1, InnoPerf goes up by 0.256 (Table 4).

Table 4. Results of path analysis for the whole sample of enterprises from 14 EU member states, total effect, direct effect, and indirect effect

Variables	Total effects			Direct effects			Indirect effects		
	PublSuppEU	KnowAcq	InnoCoopTr	PublSuppEU	KnowAcq	InnoCoopTr	PublSuppEU	KnowAcq	InnoCoopTr
KnowAcq	0.417	0.000	0.000	0.417	0.000	0.000	0.000	0.000	0.000
InnoCoopTr	0.256	0.357	0.000	0.107	0.357	0.000	0.149	0.000	0.000

EU. European Union.
Source: Own elaboration based on results of path analysis.

For each country sample, a separate model has been constructed[2].

Results for Spanish (ES) enterprises show that there is positive relation between public financial support from EU and knowledge acquisition, as well as innovation cooperation and innovation performance. Thus, all hypotheses—H1, H2, and H3—were confirmed.

Results for Bulgarian (BG) enterprises show that there is positive relation between public financial support from EU and knowledge acquisition, as well as innovation cooperation. There is no direct impact of public financial support on innovation performance. Thus, hypotheses H1 and H3 were confirmed, and H2 was rejected. Similar results (hypotheses H1 and H3 confirmed and H2 rejected) were obtained for enterprises from Cyprus (CY), the Czech Republic (CZ), Greece (EL), Croatia (HR), Hungary (HU), Lithuania (LT), and Portugal (PO).

Results for Norway (NO) and Slovakia (SL) show that there is no relation between public financial support from EU and knowledge acquisition, as well as innovation performance. However there is positive relation between public financial support from EU and innovation cooperation. Thus, hypotheses H1 and H2 were rejected, and H3 was supported.

Results for Estonian (EE) enterprises show that there is no direct impact of public financial support on knowledge acquisition, innovation cooperation, and innovation performance. Thus, hypotheses H1, H2, and H3 were rejected. Similar results were gathered for Latvian (LV) and Romanian (RO) enterprises.

Due to the limited space, we do not present these results fully as well as the results on the mediating effect of PublFinSupp for every single country. The selected results of all path analyses that are related to the hypotheses H1–H3 for each single country are all presented together in Table 5 and Figure 2.

In order to have a clear comparison of the obtained results, the standardized estimates for input additionality and behavioral additionality for each singe country are presented in the form of the figure.

It is clearly visible that there are four groups formed.

Bulgaria, the Czech Republic, Lithuania, and Portugal form the group "high input additionality, high behavioral additionality" where the public financial support has the highest impact in both dimensions.

The other group named "high input, low behavioral additionality" is formed by Cyprus and Hungary, where both dimensions are visible but input is higher than behavioral additionality.

The third group, named "low input additionality, high behavioral additionality," embrace Greece and Spain. Here, again both additionality dimensions are visible, although opposite to the second group, the behavioral additionality is stronger. For Norway and Slovakia, only behavioral additionality was detected.

2 Due to the limited space, the detailed calculations for each country are presented only partly in Table 5, full results are available on request from mlewando@sgh.waw.pl

Table 5. Taxonomy of EU innovation activity support within surveyed countries results from path models for each country sample and verification of hypotheses

Additionality type	H	BG	CY	CZ	EE	EL	ES	HR	HU	LT	LV	NO	PO	RO	SK
Input additionality standardized	H1	0.188	0.199	0.125	0.076	0.082	0.061	0.107	0.173	0.146	0.053	0.004	0.122	0.075	0.058
Input additionality P value	H1	***	***	***	0.244	**	***	**	***	***	0.538	0.866	***	0.501	0.252
Input additionality (external R&D)	H1	+	+	+	No	+	+	+	+	+	No	No	+	No	No
Output additionality standardized	H2	0.019	0.045	0.013	0.029	-0.024	0.041	-0.022	-0.015	0.052	0.173	0.033	0.012	0.056	0.001
Output additionality P value	H2	.457	0.433	0.595	0.695	0.522	**	0.590	0.566	0.082	0.388	0.159	0.590	0.614	0.987
Output additionality	H2	No	No	No	No	No	+	No	No	No	No	No	No	No	No
Behavioral additionality standardized	H3	0.184	0.116	0.209	0.023	0.207	0.286	0.125	0.146	0.180	0.173	0.233	0.290	0.198	0.195
Behavioral additionality P value	H3	***	0.038	***	0.755	***	***	**	***	***	0.058	***	***	0.066	***
Behavioral additionality	H3	+	+	+	No	+	+	+	+	+	No	+	+	No	+
Policy type		B.ID	BI.D	BI.D	NO.AE	BI.D	MULT	BI.D	BI.D	BI.D	NO.AE	MONO.D	BID	NO.AE	MONO.D

BI.D, bi- dimensionality; EU, European Union; MONO, mono-dimensionality; MULT, multudimensionality; NO.AE, no additionality effects; R&D, research and development.
***$p < 0.001$; **$p < 0.002$; *$p < 0.05$.
Source: Own elaboration based on the results of path analysis.

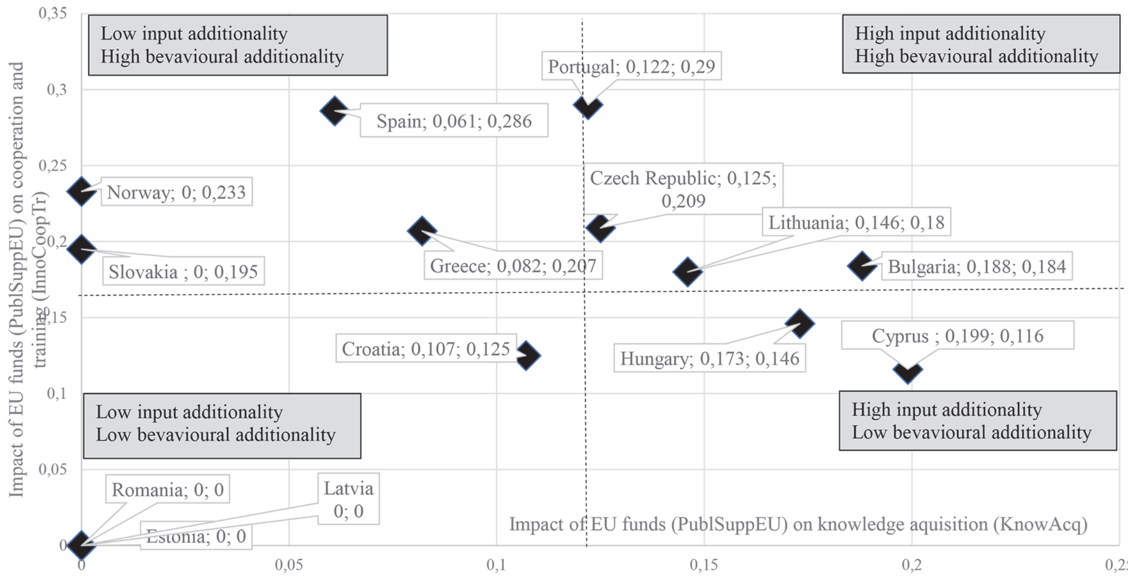

Figure 2. Results of path analysis for selected EU countries—input additionality and behavioral additionality.
Source: Own elaboration based on the results of path analysis of 14 countries under study. EU, European Union.

The fourth group “low input, low behavioral additionality” is formed by only one country: Croatia. In Estonia, Latvia, and Romania, no input nor behavioral additionality was detected.

5 Discussion and conclusions

Using the concept of additionality, this study examined the efficiency of public support for innovation. A comparison of results for the 14 selected countries revealed that there have been huge differences among these countries with regard to the effects of the EU financial support for innovation.

The support for R&D&I in all three types of additionality (input, output, and behavioral) was confirmed for the sample of enterprises originated from 14 EU countries studied together. Also, the indirect influence of public support on performance was revealed in the case of cooperation in innovation and personnel training. It has to be underlined that our results are in line with the findings of Pang et al. [2020] who also proved the existence of a mediating role of innovation resource input and cooperation in the impact of technology policies on innovation performance.

However, the analysis of individual countries from our sample brought different results. Only in one of the 14 analyzed EU countries—Spain—EU funds supporting R&D&I had a positive impact on all three areas, that is, innovation inputs, outputs, and behavioral changes. In eight EU countries, EU support resulted in input and behavioral additionality. In the two EU countries from the studied sample, only one type of additionality occurred, while in the remaining two countries, no effects of the EU support to innovation were confirmed. This somehow is in line with finding of Grabowski and Staszewska-Bystrova [2020], which proved input additionality of the support for R&D&I from the EU budget for a group of “new” EU member states, while in the “old” EU countries, stronger output additionality was revealed. Consequently, the results of path analysis revealed *multi-dimensional additionality* effects (impact of support from EU funds on knowledge acquisition, innovation cooperation, and innovation performance) only for enterprises from Spain (ES). *The bi-dimensional* impact (on knowledge acquisition and innovation cooperation and personnel training) was found for Bulgaria (BG), Cyprus (CY), the Czech Republic (CZ), Greece (EL), Croatia (HR), Hungary (HU), Lithuania (LT), and Portugal (PO). Not only the existence of additionalities was detected but also the differences in the strength of the public financial support were shown. The *mono-dimensional* impact of EU financial support on innovation cooperation and personnel training was confirmed for Norway (NO) and Slovakia (SK). No impact of financial support was observed among enterprises from Estonia (EE), Latvia (LV), and Romania (RO).

In this context, the question arises about the reasons of these differences between the European countries in terms of the scale of the additionality effects. In majority of studied countries, only bi-dimensional additionality related to the impact of R&D public grants on knowledge acquisition and personnel training occurred, while no increase in the innovation output was confirmed. A few following reasons derived from the literature for this can be considered, indicating new avenues for future research on this topic:

- Time lag between R&D grants and their effects [Dimos et al., 2021].

There is a time lag between the grant absorption and output. The study on U.K. firms found that output additionality occurs at least 3 years after the receipt of R&D grants, while input and behavioral additional effects may be seen much earlier [Dimos et al., 2021]. This temporal effect of R&D grants may be one of the reasons why output additionality occurred only in one studied country. Therefore, provided new data availability, it could be interesting to conduct a similar study after a few years taking into account a time lag between grant receipt and expected output additionality effects.

- R&D program complementarity and critical mass argument [Radicic and Pugh, 2017].

As the literature suggests in countries where European, national, and regional/local programs complement each other, stronger additionality effects can be expected due to synergies that may be achieved, thanks to combining funds from different sources as well as due to achieving critical mass in fund absorption [Czarnitzki and Lopes-Bento, 2014; Radicic and Pugh, 2017]. In this work, we studied the EU grants, but we did not look at the effects of national or regional grants. In some countries (e.g., Spain), funding from national and regional budgets plays a much more important role than in other countries (e.g. the Czech Republic) [Weresa and Lewandowska, 2014]. Furthermore, there are differences between the analyzed countries in their innovation performance (e.g., Spain and the Czech Republic were classified as moderate innovators, while Latvia, Romania, and Bulgaria as modest innovators; see IUS, 2014, p. 5). Thus, innovation policy design and implementation combined with current innovation performance may have an impact on the real absorption of EU funds.

- Firm characteristics: Internal financial potential, absorptive capacity, and experience in managing EU grants by the recipients [Bye et al., 2019; Nilsen et al., 2020].

Differences in firms characteristics in European countries may explain Spanish firms' success in delivering multidimensional additionality from public support as they have longer experience than firms from Central and Eastern Europe in applying and utilizing R&D grants from the EU to support their innovation activity.

- Design of R&D grants as supply-side policy instruments focused on direct support of innovation input (i.e., R&D efforts) and supporting innovative output (i.e., introduction of new products and processes on the market) indirectly only [Edler et al., 2013, Becker, 2015].

Our results indicate that the simple policy instruments, such as grants or subsidies, may not be fully effective, at least in a short run in supporting innovation output. R&D grants can be compared to public procurement. Therefore, there is a need for new and more sophisticated policy tools that can be offered to enterprises at the European level. Albors-Garrigos and Barrera [2011] measuring the impact of European subsidies speculated that the lack of their impact results from their influence on pre-commercial research, rather than commercialization.

As the EU grants for R&D&I differs across EU member states, it can be concluded that there is still room for improvements with regard to European innovation policy design and implementation in order to make it more effective. It seems that a traditional approach that focused on mitigating market failures and transfer of best practices from other countries is not sufficient anymore as the policy rationales have been extended to cover societal challenges. This conclusion goes in line with a mission-oriented approach to innovation policy [Mazzucato, 2018] as well as with recent findings of Uyarra et al. [2020] and Geels [2020] and seem to be even more important in the turbulent times of the coronavirus disease (COVID-19) pandemic.

This study is not without limitations. First, it must be noted that it is positioned within the science, technology, and innovation research approaches, which give main emphasis to promoting R&D and creating access to explicit codified knowledge, and does not discuss the "doing, using, and interacting" approach [Jensen et al., 2007], according to which innovation strategies are mainly based on learning and interacting. Another limitation is related to data availability. Despite the representativeness of the initial sample of firms, the extracted number of innovative firms is relatively small. In addition, the overrepresentation of the entities from Bulgaria may bias the results for the aggregated sample. It should be also noted that especially while examining the impact of public financial support, the CIS data should be used cautiously as they are anonymous, and therefore, it is not possible to conduct a follow-up survey based on more than one period of observations, which would be beneficial especially in the case of output additionality, where the effects may be postponed.

We also have to mention that even though the methodical reflection on the consequences of innovation policy in the three dimensions of the additional effect is the strength of our approach, when assessing the impact of innovation policy, it is critical to also consider interactions at various levels (regional, national, and supranational), diverse support tools that interact with other tools, and the diversity of the entities supported [Chaminade and Edquist, 2010, Magro and Wilson, 2013; Guerzoni and Raiteri, 2015]. Researchers also prove that there is a direct interrelation between different types of additionality [Czarnitzki, Licht, 2006; Hegerty et al., 2022], which we have not investigated.

Despite these limitations, our study is consistent with more general evidence of the positive role of cooperation on innovation performance of enterprises. A deeper understanding of the effects of innovation cooperation at firm-level and its underlying mechanisms is a prerequisite for a future design of policies fostering the cooperation-friendly environment. The constructed models, which highlight the importance of external behavioral additionality, may help policy authorities to develop a better understanding of how policy contributes to support innovation cooperation especially within transition economies that constitute for the vast majority of the sample.

The analysis points to the possible fruitfulness of further research on connections between innovation performance, cooperation, and public financial support as well as on reasons concerning differences between European countries regarding additionality dimensions. This article also provides evidence for the managers of innovative firms about additional effects of public R&D funds, especially in the context of innovation cooperation, which is still limited in many European countries.

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