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Patterns of Interrelationships between Inflation, R&D, Innovation, and Economic Growth: Evidence from Central and Eastern European Countries

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Abstract

The primary objective of the article is to examine the nexus between inflation, R&D, patents, and economic growth within a group of Central and Eastern European countries (CEECs). The examination is conducted in two parts. First, the impact of total R&D expenditures on economic growth is observed, as well as the influence of growth on private and public R&D investments. Second, the conversion from private and public R&D investment to innovation, measured by the number of patents, is observed. Throughout the analysis, economic growth and inflation are representative of macroeconomic stability. The outcomes of the panel auto-regressive distributed lag estimation indicate that total R&D

expenditures are essential and positively significant for economic growth in the observed countries. The results also show that output growth has a remarkably positive impact on generating private R&D expenditures. Such an influence is also found, but at a weaker level, in the case of public R&D expenditures. In this part of the analysis, inflation has demonstrated a harmful influence on R&D expenditures. The results of the second part indicate that public and private R&D expenditures, at a significant level, generate innovation activities, while the impact of inflation has proven to be unimportant.

Keywords: innovation, economic growth, inflation, panel ARDL

JEL classification: C33, E31, O11, O30

1 Introduction

Findings from previous studies disclose numerous determinants that cause innovation in different phases (Stojčić & Hashi, 2014). A central role in generating innovation and economic growth, apart from establishing an auspicious macroeconomic and institutional framework, is played by the scope of investment in R&D. The legacy of the socialist period is the absent advantage of Central and Eastern European countries (CEECs) in indications of the volume of R&D. In the transition period, the economic progress of these countries was promoted by determinants other than R&D investment, given that the boost in productivity was followed by a reduction in the volume of R&D expenditures (Radošević, 2005). Productivity growth was prompted by a remarkable increase in output growth and a drop in employment since, in the period of the restructuring process, the opening of new firms with efficient production crowded out inefficient businesses in CEECs (Van Ark & Piatkowski, 2004). The post-transition period required innovative sources of incentives to improve productivity, within which R&D investment has become a relevant driver of economic progress in CEECs. CEE innovation and R&D policies arising in the early and mid-2000s have

directed investors to focus on high technology sectors, technology parks for start-ups, and related purposes (Kattel, Reinert, & Suurna, 2009). As Radošević (2017) points out, the post-2008 difficulty for CEECs is how to shift their economies onto a course of progress that is encouraged by investments and enhancements in productivity, considering that development in the observed economies is not based on research-driven innovation. Alternatively, CEECs rely on the cooperation of domestic R&D with more advanced technology from imported inputs. In that sense, with an aim to create a dynamic economic growth, a notable role in CEECs should belong to the innovation-driven system encouraged by the domestic macroeconomic environment.

To the best of our knowledge, this is the first study that takes into account the link between economic progress, inflation, and innovation in CEECs. Previous studies on the CEE region have observed the connection between economic growth and innovation, not taking into account inflation (Howells, 2005; Çetin, 2013; Pradhan, Arvin, Hall, & Nair, 2016), or have examined the relationship between growth and inflation without regard to innovation (Hasanov & Omay, 2011; Khan & Hanif, 2020). The first effort to estimate the connection between innovation, inflation, and economic growth was the study of Ramzi and Wiem (2019), who set these relations, but did so on a sample of 25 countries divided into the most innovative and the less innovative countries. It is important to note that the level of innovation in our study is observed through two indicators: R&D intensity and the number of patents. In addition, the innovativeness of our study is reflected in the use of two other sorts of R&D funding origins (public and private), which Ramzi and Wiem (2019) specifically pointed out as lacking in the research.

The central intention of the article is to seek regularities over the nexus between inflation, R&D, patents, and economic growth. In line with the defined research interests, the main objective is to recognize the characteristics of the interrelationships between the mentioned economic categories. More precisely, the paper considers the relations between each of the analyzed variables. Thus, the

main aim is to identify the short-run and long-run influences between inflation, economic growth, and innovation outcomes. An additional aim is to investigate whether there is a causality between the stated macroeconomic indicators and innovation, as well as the direction of the causality.

According to the described intentions of the paper, five main hypotheses can be derived:

H_1: R&D expenditure positively affects economic growth in the CEECs.

H_2: Economic growth positively affects both private and public R&D investment in the CEECs.

H_3: Private and public R&D investment have a positive impact on patenting activity in the CEECs.

H_4: Higher inflation represents a limiting determinant to R&D investment, patenting activity, and economic growth in the CEECs.

H_5: In the short run, one-way causality tends to be more dominant compared to two-way causality between R&D, innovation, inflation, and economic growth.

The paper's structure is organized in the following manner. After the introduction, the relevant findings of empirical literature related to the topic of research are evaluated. The subsequent section offers an explanation of the data used and the methodology applied. Then, the outcomes of the tests are reported. The accompanying discussion allows the obtained results to be interpreted objectively. Lastly, basic findings and notes for further research are summarized.

2 Literature Review

Multiform tests have provided quite compelling evidence that economic growth is determined by the volume of R&D expenditures (Braconier & Sjöholm, 1998; Lee, 2005; Guloglu & Tekin, 2012). Various econometric approaches have been

used to address the relationship between R&D and growth within certain groups, such as G7 (Wälde & Woitek, 2004) or European Union (EU) countries (Athina, Athanasios, Panagiotis, Zacharias, & Dimitrios, 2018). Comparative analysis of innovation policies in 28 OECD countries shows that the pattern of R&D expenditures that influence growth differs from country to country. Mainly, those differences are determined by the countries' specific socio-economic frameworks (Pessoa, 2010). Akcali and Sismanoglu (2015) compared a sample of 19 developing and developed countries to test their R&D efficiency from 1990 to 2013. The authors found that economic growth in the United Kingdom, France, and the Netherlands was remarkably boosted by R&D investments – an increase of approximately 1 percent in R&D expenditures raises growth by around 1 percent. Using a panel of 11 OECD countries for the period between 1981 and 2000, Chen, Chu, Ou, and Yang (2015) detected a robust impact of R&D investments on economic growth, through development-oriented industries or process innovation-oriented industries. The evidence of Bravo-Ortega and Marín (2011) suggests that R&D expenditures per capita represent an important factor in technological development and economic growth. The findings particularly point to high returns from R&D in middle-income countries and even higher in low-income countries.

Some recent studies focus on innovation economics in CEECs. Švarc and Dabić (2019) outline that, despite the transformation from socialism to capitalism, the basic mechanisms of economic functioning, such as strong state paternalism, lack of competition, private initiatives, and weak innovativeness, remain the main limitations of development in CEECs. Also, Smętkovski and Wójcik (2012) acknowledge that one of the omnipresent characteristics in all post-communist countries is the relatively weakened innovation potential and centralization of the technological infrastructure. Thus, the interconnections between the existing competitive core and less developed periphery in these countries need to be reinforced (Stojčić, Aralica, & Anić, 2019). The findings of Stojčić (2020) confirm a very low level of innovation capacity in CEECs, and underutilized

potential of cooperation with other EU countries (Stojčić & Orlić, 2019). These collaboration channels should be an important solution for the better valorization of the innovative capacity in less developed regions of CEECs.

A multiple autoregressive model analysis showed that innovation, expressed through the number of patents, and the level of R&D expenditures exert a strong influence on economic growth in CEECs (Pece, Simona, & Salisteanu, 2015). Further, to examine the influence of innovation on economic growth in CEECs, Sener and Tunali (2017) utilized an unbalanced panel dataset incorporating the period between 1993 and 2014. The outcomes, based on the panel ARDL model, display that R&D expenditures have no consequence on economic growth, while patents have a positive impact on economic growth in the long run. Additionally, empirical results reveal that patents negatively influence economic growth in the short run. The negative effect of patents stems from the fact that a longer period and a significant scope of R&D expenditure are needed for patents to become profitable and thus spur economic growth. On the other hand, the development level of a country is a generator of innovation, which enables funds to be allocated to R&D and represents the main origin of support to the innovation process in CEECs (Petrariau, Bumbac, & Ciobanu, 2013). The authors point out that CEECs have accelerated economic progress, but growth is not based on the innovation process, since innovation is in a catch-up process, compared to the growth rate. Based on the presented studies, it is not possible to derive a singular conclusion about the nexus between economic growth and innovation in CEECs, considering that the results depend on the indicators used to represent innovative activity in these countries.

In line with one of the topics of the paper, it is also necessary to reveal the effects of economic growth on R&D investment and innovation outcomes. Santos and Catalão-Lopes (2014) used a group of EU countries to search for such transposed relation. The results of a Granger causality test confirmed the reverse impact of growth on R&D only in the case of Spain and France. According to the analysis, dynamic economic growth creates the conditions for higher reinvestment in

the future. Thus, more funds can be utilized to foster R&D activities. Another interesting approach was recently taken by Mtar and Belazreg (in press) in an aim to identify the nexus between financial development, economic growth, and productivity as a proxy for innovation in OECD countries. Applying the vector auto-regressive (VAR) procedure, the authors came to several significant conclusions. In addition to the well-known impact of R&D and the financial system on growth, the new findings show that output growth leads to productivity improvement in 10 out of 27 observed countries. However, the bidirectional link between economic growth and innovation was confirmed only in Spain and Sweden. Howells (2005) emphasizes that positive growth rates can encourage the spread of innovation. On the other hand, a two-way nexus between economic growth and innovation was confirmed in the case of 18 eurozone countries (Pradhan et al., 2016), but also in a study that included nine EU countries (Çetin, 2013).

In addition to clear findings on interrelations between innovation and growth, important causality effects between economic growth and inflation can also be verified. Undoubtedly, the inflation-growth relationship represents one of the most important perspectives in the evaluation of macroeconomic conditions. Hasanov and Omay (2011) used a bivariate GARCH approach to examine the coherency between inflation and economic growth in CEECs. The results indicated that the inflation rate induces uncertainty in both inflation rate and output growth rate, which is detrimental to real economic activity. Additionally, positive growth rates proved to decrease macroeconomic instability in some analyzed countries. Similarly, based on the system GMM model, Khan and Hanif (2020) supported the results of previous research, which showed that the correlation between inflation and economic growth is predominantly determined by institutional quality. Thus, the general conclusion could be that inflation-growth causality depends on wider socio-economic circumstances.

By using the Granger causality test, Ramzi and Wiem (2019) have made an indicative leap in research on the mutual relations between inflation, innovation,

and economic growth. Working on a comprehensive sample of 25 countries, the authors outlined two interesting observations. First, innovation productivity is shown to be more responsive to inflation in the most innovative countries. Second, innovation funding is more sensitive to inflation in countries with weaker innovation results.

To outline, the central research issues in the article encompass different aspects of the nexus between inflation, R&D, innovation outputs, and economic growth. The following section describes the model we used to determine the relationships between the observed variables.

3 Methodology and Data

The study incorporates panel data series ranging from 2002 to 2017 and including eleven CEECs (i.e., Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia). Since the central intention of the research is to investigate the nexus between innovation, economic growth, and inflation, the following indicators of these macroeconomic categories are used: gross domestic product per capita in euros (variable GDP_PC) – as an indicator of economic growth; harmonized index of consumer prices, annual average rate of change (variable HCPI) – as a representative for inflation; number of patent applications to the European Patent Office (EPO) by priority year, per million inhabitants (variable PATENTS), and R&D expenditures by sector of performance, as percentage of gross domestic product (variable R&D_TOTAL, R&D_PRIV, R&D_PUB) – as proxies for innovation. The variables R&D_ TOTAL, R&D_PRIV, and R&D_PUB are R&D expenditures generated by all sectors, the business enterprise sector, and the government sector, respectively. The statistical office of the European Commission (Eurostat, 2020) was used as the source of data. The following tables present the descriptive statistics of the variables as well as the correlations amongst them. As exhibited in Table 1, R&D_PUB and GDP_PC reflect normal skewness and are platykurtic, while

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R&D_TOTAL, R&D_PRIV, PATENTS, and HCPI are positively skewed and leptokurtic. Furthermore, the Jarque-Bera statistic reveals the absence of normal distribution for all series except the series of R&D_PUB and GDP_PC. The explanation might be a cross-sectional and heterogeneous character of the data, which are adjusted during the examinations in panel data analysis.

Table 1: *Descriptive Statistics of the Variables*

Variable	R&D_TOTAL	R&D_PRIV	R&D_PUB	PATENTS	GDP_PC	HCPI
Mean	0.948409	0.481761	0.209943	14.57290	10174.60	3.178977
Median	0.835000	0.340000	0.200000	8.470000	10210.00	2.600000
Maximum	2.560000	1.960000	0.390000	69.10000	20810.00	22.50000
Minimum	0.360000	0.090000	0.020000	0.520000	2220.000	-1.600000
St. dev.	0.489604	0.390627	0.071526	15.48356	4120.547	3.323606
Skewness	1.250848	1.665021	0.357553	1.845999	0.256847	2.026498
Kurtosis	4.200665	5.741008	2.993547	5.779572	2.489674	10.16705
Jarque-Bera	56.46724	136.4169	3.750399	156.6170	3.844974	497.1513
Probability	0.000000	0.000000	0.153324	0.000000	0.146243	0.000000
Obs.	176	176	176	176	176	176

Source: Authors' calculations.

Concerning the additional characteristics of the series, it is essential to determine the correlation between the selected variables. As shown in Table 2, a strong positive correlation is detected between economic growth and R&D expenditures generated by all sectors and the business enterprise sector. A moderate positive correlation is identified between economic growth and R&D expenditures created by the government sector. When examining the link between the two measures of innovation (patents and R&D expenditures), a positive correlation is observed. Lastly, economic growth, R&D expenditures, and patents are negatively correlated with inflation.

Table 2: *Correlation Matrix of the Variables*

	R&D_TOTAL	R&D_PRIV	R&D_PUB	PATENTS	GDP_PC	HCPI
R&D_TOTAL	1					
R&D_PRIV	0.90	1				
R&D_PUB	0.40	0.28	1			
PATENTS	0.79	0.77	0.28	1		
GDP_PC	0.69	0.67	0.22	0.82	1	
HCPI	-0.25	-0.25	-0.12	-0.32	-0.41	1

Source: Authors' calculations.

In the analysis, R&D expenditures are designated as input measures, while patents represent output measures of innovation activities. Consequently, the analysis is divided into two parts. The first part involves studying the links between economic growth, inflation, and R&D expenditures. Considering that economic growth is generated by total R&D in the economy, the intention is to detect how R&D expenditures generated by all sectors and inflation impact economic growth. Additionally, since R&D expenditures are perceived as input measures of innovation activity, it is relevant to analyze how essential macroeconomic conditions in former transition economies support these dimensions of innovation. To that end, the first part of the analysis covers R&D expenditures divided into: R&D expenditures generated by the business enterprise sector and R&D expenditures generated by the government sector, considering that these are the main sectors of the economy, which by their nature generate the highest amount of R&D expenditures. Therefore, the first part of the research includes three different forms of analysis of these relations:

$$GDP_{\_PC} = f\left(R\&D_{\_TOTAL}, HCPI\right); R\&D_{\_PRIV} = f\left(GDP_{\_PC}, HCPI\right); R\&D_{\_PUB} =$$
$$= f\left(GDP_{\_PC}, HCPI\right).$$

In the second part of the analysis, the relationship between patents, R&D expenditures, and inflation is determined. The main question is whether R&D expenditures generated by the business enterprise sector and the government

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sector, combined with inflation, impact patents. Accordingly, two different models are used in examining these relations:

$$PATENTS = f\left(R\&D_{\_PRIV}, HCPI\right); \quad PATENTS = f\left(R\&D_{\_PUB}, HCPI\right).$$

The initial step that has to be made in investigating the relationships between innovation, economic growth, and inflation in the CEECs, is to examine cross-sectional dependence in panel data analysis. Analyzing cross-sectional dependence is a vital step, necessary to decide on suitable mechanisms for investigating the integration of the data and for the consequent evaluation of the model. The influence of cross-sectional dependence in the assessment frequently depends on a variety of determinants, such as the magnitude of the correlations over cross-sections and the characteristics of the cross-sectional dependence itself (De Hoyos & Sarafidis, 2006). Different sources of cross-sectional dependence can range from the presence of a dominant unit in the panel data setup (common factor influencing all time series) to cross-sectional dependence that can be significant only amid some neighbors (such as states, regions, trade partners) (Banerjee & Carrion-i-Silvestre, 2017). To examine the cross-sectional dependence of cross-sectional units, two tests are used: Breusch-Pagan LM test and Pesaran-scaled LM test. The Lagrange multiplier, developed by Breusch and Pagan (1980), is satisfactory for the panel if N is comparatively small and T is sufficiently large (which is the case in the analysis: N=11, T=16). The test is based on the following LM statistic (Baltagi, Feng, & Kao, 2012):

$$LM = \sum_{i=1}^{N-1}\sum_{j=i+1}^{N} T_{ij}\hat{p}_{ij}^2 \rightarrow X^2 \frac{N(N-1)}{2}, \tag{1}$$

where $\hat{p}_{ij}$ is the correlation coefficient of residuals, as well as in the Pesaran-scaled LM test, which can be estimated as (Baltagi et al., 2012):

$$LM_{pesaran} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T_{ij}\hat{p}_{ij}^2 - 1\right) \rightarrow N(0,1). \tag{2}$$

Considering the high level of interactivity in the functioning of economies of the analyzed countries, spatial spillover consequences, which are one of the foundations of cross-sectional dependence, become more likely. Supposing that the panel data in the analysis will exhibit cross-sectional dependence, the following step defines the selection of second-generation panel unit root tests (which implies that cross-sectional units are cross-sectionally dependent) to determine the nature of the stationarity of the series. Pesaran (2007) proposed a unit root test known as the cross-sectionally augmented Im, Pesaran, and Shin (CIPS) test, which can be expressed as:

$$CIPS(N,T) = N^{-1} \sum_{i=1}^{N} t_i(N,T), \qquad (3)$$

where CIPS*(N,T)* is the cross-sectionally augmented Im, Pesaran, and Shin test, as mentioned above, and $t_i(N,T)$ is the cross-sectionally augmented Dickey-Fuller statistic for the ith cross-sectional unit (Pesaran, 2007).

Nonstationarity difficulties and inaccurate presumption of the homogeneity of the slope coefficient frequently occur in analysis including time-series and cross-sectional data. Accordingly, the panel auto-regressive distributed lag (ARDL) model is applied in the article. The method is suitable considering that the potential long-run and short-run nexus between economic growth, inflation, and innovation can be considered regardless of the order in which the variables are integrated. Pesaran and Smith (1995) and Pesaran, Shin, and Smith (1999) proposed two different estimators as the solutions to heterogeneity bias produced by heterogeneous slopes in traditional panel fixed and random effects estimates: mean group (MG) and pooled mean group (PMG). The distinction between these two estimators is that MG is more compatible within the premise that both slope and intercepts are permitted to differ among the countries, while PMG is compatible under the condition of long-run slope homogeneity (Ndambendia & Njoupouognigni, 2010). Regarding the PMG estimator, the reason behind the long-term uniformity of the coefficients is the assumption of existing common factors that affect all cross-sectional units in the corresponding model. On the

other hand, the MG estimator does not take into account the fact that certain parameters may be similar over the group (Pesaran, Shin, & Smith, 1997). The selection between the MG and the PMG estimator is based on the Hausman test. If the Hausman test fails to discard the long-run homogeneity restriction, then the PMG estimator is more suitable, and vice versa.

Lastly, to adequately comprehend the links between economic growth, inflation, and innovation, the Dumitrescu-Hurlin (2012) panel Granger causality test is implemented. Two specific distributions are developed within this test: asymptotic and semi-asymptotic distribution. Asymptotic distribution is applied when T is greater than N (which is the case in the analysis: $N=11$, $T=16$), while semi-asymptotic distribution is used when N is greater than T (Dumitrescu & Hurlin, 2012). The null hypothesis implies that there is no causal relationship for any of the units of the panel. The null and the alternative hypothesis can be expressed as:

$$H_0 : \delta_i = 0 \quad \forall_i = 1, \dots Z \tag{4}$$

$$H_1 : \delta_i = 0 \quad \forall_i = 1, \dots Z_1$$
$$\delta_i \neq 0 \quad \forall_i = Z_1 + 1, \ Z_1 + 2, \ \dots, \ Z \ , \tag{5}$$

where Z_1 provides the condition $0 \leq \dfrac{Z_1}{Z} \leq 1$. The circumstances in which $Z_1 = Z$, are equivalent to the null hypothesis, and if Z_1 is zero, the causality for all cross-sections in the model is confirmed.

All variables, except HCPI, are represented using logarithmic expressions and can be perceived as elasticities. The following section describes the results of the conducted analysis.

4 Results and Discussion

Analyzed from the aspect of strong intra-economic linkages of macroeconomic data, the cross-sectional independence amongst certain groups cannot be assumed; rather, the premise needs to be questioned. Table 3 notes that the null hypothesis of cross-sectional independence is rejected at a 1 percent level of significance for each variable. Cross-sectional dependence testing is of great significance for defining unit root tests, which determine the order of integration of the variables. As the assumption of cross-sectional independence is rejected, further analysis suggests the utilization of second-generation unit root tests. The results of the CIPS test are also presented in Table 3, which shows that all variables, except HCPI, are nonstationary at the level. Nonetheless, every nonstationary variable (R&D_TOTAL, R&D_PRIV, R&D_PUB, PATENTS, and GDP_PC) becomes stationary after the first difference, according to the CIPS test. The presence of a mixed order of integration supports the use of the panel ARDL model.

Table 3: *Cross-Sectional Dependence and Unit Root Tests Results*

Variable	R&D_TOTAL	R&D_PRIV	R&D_PUB	PATENTS	GDP_PC	HCPI
Breusch-Pagan LM	377.8468 (0.0000)	298.2892 (0.0000)	209.8733 (0.0000)	424.9460 (0.0000)	831.1506 (0.0000)	348.2119 (0.0000)
Pesaran-scaled LM	30.78224 (0.0000)	23.19672 (0.0000)	14.76659 (0.0000)	35.27297 (0.0000)	74.00306 (0.0000)	27.95666 (0.0000)
CIPS (level)	-1.897	-1.873	-1.882	-2.596	-2.153	-2.974*
CIPS (first difference)	-3.194*	-3.165*	-4.366*	-4.482*	-2.867*	-4.456*

Notes: Figures in parentheses are *p*-values. * denotes rejection of the null hypothesis of unit root.
Source: Authors' calculations.

As the overall analysis is divided into two parts, the fundamental links between economic growth, inflation, and R&D expenditures are the first to be investigated. Table 4 shows the information on long-run elasticities, the results of the Hausman test, as well as the measures of the speed of adjustment towards the long-run equilibrium (ECT) for the whole panel and for the individual

countries. Concerning all of the set models, the Hausman test failed to reject the long-run homogeneity restriction (*p*-value is higher than 0.05), indicating the appropriateness of the PMG estimator when it comes to considering the relationship between economic growth, inflation, and R&D expenditures. The Akaike information criterion (AIC) is used to determine the lag-length for each regression. From the section of Table 4 that reports the long-run links between the observed variables, it can be established that:

- A 1 percent increase in R&D expenditures generated by all sectors boosts economic growth by 0.3398 percent, while a rise of 1 percent in inflation decreases economic growth by 0.0546 percent.

The outcome of the analysis confirms H_1, which assumes that R&D positively affects economic growth. The outcomes on long-term elasticities confirm that R&D expenditures generated by all sectors have a significant positive impact on economic growth, while on the other hand, inflation harms economic growth in the long run. Thus, the negative impact of inflation on economic growth confirms the statement of H_4. The obtained results support the assertion that R&D investment can be well utilized in reducing the gap between new and old EU member states (Petrariu et al., 2013). However, the real effects of R&D spending in CEECs are still lower than those achieved in developed EU countries (Freimane & Bāliņa, 2016). Examining a comprehensive sample of variables, Próchniak (2011) outlined that low inflation represents one of the favorable economic growth determinants.

- A 1 percent change in economic growth increases R&D expenditures generated by the business enterprise sector by 0.7601 percent, while a rise of 1 percent in inflation decreases private R&D expenditures by 0.0137 percent.

- A 1 percent rise in economic growth increases R&D expenditures generated by the government sector by 0.1476 percent, while a growth of 1 percent in inflation reduces government R&D expenditures by 0.0273 percent.

It is observed that R&D expenditures are positively influenced by the movement in economic growth, while inflation exerts a negative impact on the measures of innovation in the long run. The findings verify H_2, which states that economic growth has a positive influence on both private and public R&D investment. Also, the negative impact of inflation on private and public R&D corresponds with the assumption expressed in H_4. The described relationship between economic growth and R&D investment is the subject of a smaller number of studies. Nevertheless, our results are theoretically comparable to the previously mentioned findings of Çetin (2013), Santos and Catalão-Lopes (2014), Pradhan et al. (2016), and Mtar and Belazreg (in press). The results on the negative influence of inflation are in line with previous conclusions that higher inflation rates can damage economic growth (Hung, 2003; Pradhan, Arvin, & Bahmani, 2015; Baharumshah, Slesman, & Wohar, 2016). The assumption that inflation has a similar harmful impact on R&D expenditures and innovation as on economic growth is confirmed by this part of the research.

Concerning ECT, in each model, the corresponding negative sign and significance at the level of 1 percent are observed. Hence, the results show the existence of a stable long-term cointegration between the variables. Further attention in the study is placed on how long it will take, after the shock, for the current imbalance to be reduced by 50 percent in the analyzed countries. The cases of countries where stable long-term relationships between the variables exist but are not significant for the target variable (statistically insignificant ECT with a negative sign) are excluded from consideration.

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Table 4: *Pooled Mean Group Regression and Hausman Test Results*

Dependent variable	GDP_PC	R&D_PRIV	R&D_PUB
Long-run coefficient			
R&D_total	0.3398***		
GDP_PC		0.7601***	0.1476**
HCPI	-0.0546***	-0.0137***	-0.0273***
Error correction term	-0.1255877***	-0.3351624***	-0.3028407***
Hausman test	5.73	0.62	1.36
p-value	0.0569	0.7343	0.5056
Error correction term			
Bulgaria	-0.040218 (0.260)	-0.3120934 (0.001)	0.0302924 (0.762)
Croatia	-0.1562931 (0.00)	-0.4457353 (0.014)	-0.1728054 (0.403)
The Czech Republic	-0.0587588 (0.279)	-0.1051106 (0.224)	-0.4741401 (0.039)
Estonia	-0.1446597 (0.002)	-0.2540481 (0.112)	-0.778246 (0.005)
Hungary	-0.0943086 (0.403)	-0.1029222 (0.080)	-0.0952932 (0.175)
Latvia	-0.0578064 (0.308)	-0.3562805 (0.159)	-0.0789403 (0.680)
Lithuania	-0.0798166 (0.008)	-1.294857 (0.00)	-0.7719184 (0.000)
Poland	-0.1285139 (0.260)	0.003195 (0.972)	-0.052298 (0.848)
Romania	-0.5280303 (0.000)	-0.2737957 (0.022)	-0.0932192 (0.720)
Slovakia	-0.2065606 (0.000)	-0.2349763 (0.022)	-0.8146093 (0.001)
Slovenia	0.1135145 (0.077)	-0.3101621 (0.002)	-0.0300700 (0.863)

Notes: *, **, and ***denote significance at 10%, 5%, and 1%, respectively. Figures in parentheses are *p*-values. The optimal lag length is determined by AIC.

Source: Authors' calculations.

Table 4 indicates that, in the model where GDP_PC is the dependent variable, the shortest time required to halve the imbalance is registered in the case of Romania. The coefficient of -0.53 indicates that 53 percent of the adjustment occurred in the period prior to the equilibrium, while 47 percent of disequilibrium remains. That means the remaining imbalance will be reduced by 50 percent in less than one year. On the other hand, in the case of Slovakia, Croatia, Estonia, and

Slovenia, a period of three to six years is required to halve the imbalance. In the second model, which involves R&D_PRIV as the target variable, the longest time required to halve the imbalance is registered in Hungary (around six years), while in other countries that time is incomparably shorter (about one to three years are required in the case of Bulgaria, Croatia, Romania, Slovakia, and Slovenia). Sequentially, in the third model, where R&D_PUB is an output variable, it takes half a year to a year for the imbalance to be halved in the analyzed countries (the Czech Republic, Estonia, Lithuania, and Slovakia).

As the positive long-term influences between economic development and R&D expenditures have been recognized, as well as the long-term adverse effects of inflation, which may represent a hindrance to further economic and innovative development, it is important to examine the nexus between innovation outputs, innovation inputs, and inflation.

The following part of the analysis involves examining the most significant long-term impacts between inflation and innovation, measured by R&D expenditures (generated by the business enterprise sector and the government sector) and patents. With regard to the Hausman test, different results are achieved during the analysis of the impact of R&D expenditures generated by the government sector and inflation on patents. As observed in Table 5, the Hausman test rejects the long-term homogeneity restriction (p-value less than 0.05) in the model, which covers the impact of R&D_PUB on the target variable. That indicates the suitability of the MG estimator for further analysis in the model. In the model that estimates the impact of R&D_PRIV on patents, the p-value of the Hausman test (0.1899) indicates the greater suitability of the PMG estimator. The results of the models from Table 5 display the following:

- A 1 percent change in R&D expenditures generated by the business enterprise sector increases patents by 0.5041 percent, while a 1 percent variation in inflation increases patents by 0.0271 percent.

- A 1 percent growth in R&D expenditures generated by the government sector raises patents by 0.8254 percent, while inflation does not show a statistically significant impact on patents.

It is observed that, in both models, a rise in R&D expenditures increases growth in patents. The obtained results confirm H_3, and clearly indicate a positive impact of R&D on the growth of patenting in the CEECs. The result is in line with our assumption, as with the earlier claim of Potužáková and Öhm (2018). The authors easily proved a significant influence of R&D expenditures on growing patenting activity in Europe. However, the main statement is undermined by the additional knowledge that there are irrefutable differences in the level of R&D investment between macro-regions. Consequently, unequal spending on R&D can easily lead to real economic disparities across European regions. When considering both private and public R&D investments, our findings are also comparable to the analysis of Bilbao-Osorio and Rodríguez-Pose (2004). Their study reveals that both the government and business sectors have a notable role in fostering patent growth. The estimated results regarding the positive impact of R&D investment on innovative activities are consistent with some of the conclusions from the papers by Moreno, Paci, and Usai (2005) and Navarro, Gibaja, Bilbao-Osorio, and Aguado (2009). Further analysis shows that inflation mildly influences growth of patents in the first model, while it does not have a significant influence in the second model. The evidence deviates from the theoretical assumption presented in H_4, which suggests a negative impact of inflation on innovation in the CEECs.

Within both instances, the ECT has a negative sign and is statistically significant at the 1 percent level of significance, indicating a stable long-term association between the variables. Although the MG estimator implies the heterogeneity of long-term coefficients, the relationships between the variables for each country are not presented in the article. Instead, in order to maintain uniformity in the article, country-by-country ECT analysis is presented. In the models, countries with a negative ECT that is not statistically significant will be omitted from this part of the analysis. In the model that presents the impact of R&D_PRIV and

inflation on patents, Table 5 shows that the minimum time required to halve the imbalance is observed in the case of Bulgaria, Hungary, and Lithuania (less than one year). A slightly longer period is required in the case of Croatia, Estonia, Latvia, Slovakia, and Slovenia (from one year to two and a half years). In the case of Poland, a significantly longer time is required – about eight years to halve the imbalance. On the other hand, in the model that covers the impact of R&D_PUB and inflation on patents, it takes about the same time to halve the imbalance (less than one year in Bulgaria, Latvia, and Slovakia, while for Lithuania about one year is required).

Table 5: *Pooled Mean Group and Mean Group Regressions and Hausman Test Results*

Dependent variable	PATENTS	PATENTS
Long-run coefficient		
R&D_PRIV	0.5041***	
R&D_PUB		0.8254**
HCPI	0.0271**	0.008
Error correction term	-0.3966139 ***	-0.4307931***
Hausman test	3.32	8.23
p-value	0.1899	0.0163
Error correction term		
Bulgaria	-0.683707 (0.004)	-0.98525 (0.001)
Croatia	-0.3217222 (0.049)	-0.2842908 (0.188)
The Czech Republic	-0.1208008 (0.133)	-0.1424058 (0.469)
Estonia	-0.4102905 (0.014)	-0.3626747 (0.119)
Hungary	-0.988355 (0.000)	-0.2910383 (0.428)
Latvia	-0.2249278 (0.088)	-0.7058656 (0.010)
Lithuania	-0.5595088 (0.002)	-0.4396212 (0.072)
Poland	-0.0879329 (0.085)	-0.0532906 (0.275)
Romania	-0.0723242 (0.400)	-0.1652434 (0.530)
Slovakia	-0.432127 (0.022)	-0.7727997 (0.001)
Slovenia	-0.4610563 (0.022)	-0.5362444 (0.215)

Notes: *, **, and ***denote significance at 10%, 5%, and 1%, respectively. Figures in parentheses are *p*-values. The optimal lag length is determined by AIC.

Source: Authors' calculations.

Further analysis focuses on the examination of the short-run dynamic bidimensional causality between the variables by using the Dumitrescu-Hurlin (2012) panel Granger causality test that allows the appearance of heterogeneity over the cross-sections. The appropriate lag length is chosen based on AIC. The intention is to examine the course of causality among the variables of interest.

Table 6: *Dumitrescu-Hurlin Panel Causality Test Results*

Variable	R&D_TOTAL	R&D_PRIV	R&D_GOV	PATENTS	GDP_PC	HCPI
R&D_TOTAL	-	1.62*	19.38***	8.75***	2.12**	-0.43
R&D_PRIV	7.62***	-	2.48***	4.06***	7.20***	11.10***
R&D_GOV	9.98***	8.05***	-	5.43***	1.50	4.24***
PATENTS	-0.61	-0.79	0.37	-	3.31***	2.16***
GDP_PC	1.29	2.35***	3.59***	3.18***	-	20.78***
HCPI	2.16	2.32**	0.95	6.75***	1.83*	-

Notes: The values are the Z-bar statistics. *, **, and ***denote significance at 10%, 5%, and 1%, respectively. The optimal lag length is determined by AIC.
Source: Authors' calculations.

It can be observed from Table 6 that there is a unidirectional causality running from economic growth to R&D expenditures generated by all sectors, as well as a bidirectional causality between R&D expenditures generated by the business enterprise sector and economic growth. The results are in line with the findings of Szarowská (2018), who linked this two-way causality between private R&D and economic growth with the rising support for applied research and advancing innovative technology that can contribute to economic growth. Furthermore, the outcomes could not confirm a short-run causal connection between total R&D expenditures and inflation, while a bidirectional causality between inflation and private R&D expenditures is recorded. The results also show a one-way causality running from R&D expenditures generated by the government sector to economic growth, and a unidirectional causality from inflation to government R&D expenditures. Lastly, a unidirectional short-term causality relationship is observed between patents and R&D funds generated by the business and the government sectors, while bidirectional causal relations are discovered between

patents and inflation. The result confirming the causal relationship between R&D expenditures and patent applications is in line with the findings of Sözen and Tufaner (2019).

Lastly, H_5 assumes a more frequent one-way linkage between all analyzed variables. However, the evidence shows a two-way causality between private R&D and economic growth, private R&D and inflation, as well as between patents and inflation, indicating that the hypothesis can be partially accepted.

5 Conclusions

The general purpose of the paper was to describe the nexus between inflation, R&D funds, innovation outcomes, and economic growth in selected CEECs. The main objective was to discover interrelationships and to reveal the short-run and long-run causality between these variables. The long-run causality between the variables has been shown to be particularly indicative.

The results highlight that total R&D expenditures are important and positively significant for economic growth in the observed countries. Conversely, the study examined the impact of economic growth on private and public R&D expenditures. The basic assumption was that a favorable macroeconomic framework represents a relevant incentive for more intense investments in a knowledge-based economy. The ARDL estimation coefficients support the statement that output growth shows a remarkably positive impact on generating private R&D expenditures. Such an impact is also found, but at a weaker level, in the case of public R&D expenditures. In this part of the analysis, inflation has demonstrated a significant and negative influence on R&D expenditures.

A notable conclusion was that both public and private R&D expenditures generate innovation activities at a significant level. Sustainable and long-lasting development depends on innovation as a driving force of a country's economic

growth. In that sense, the role of R&D investment is fundamental in forming an environment for dynamic and quality development.

It has been proved that growth rates have a more significant impact on private than on public R&D investment, and that inflation exerts a similar influence on the observed sectors in the CEECs. This suggests that, in addition to macroeconomic stability, policymakers should implement programs that will boost output growth within the given timeframe. On the other hand, this insight could help create a pattern for investing in R&D, which in turn would provide higher innovation and more dynamic economic growth.

In summary, all proposed hypotheses can be accepted, in whole or in part. H_4 can be partly accepted, because of the moderate, but positive influence of inflation on patenting activity. The conducted estimation of Dumitrescu-Hurlin panel causality revealed the absence of unique findings on the nexus between growth, inflation, and innovation. The existence of a two-way causality between inflation and private R&D expenditures and inflation and innovation, in the short run, makes the assumption of H_5 partially accurate.

The major limitation of our study could stem from the set of included indicators. We composed our model by using economic growth and inflation as general macroeconomic determinants. Also, we employed data on R&D expenditures and patents to explore the level of innovation in the analyzed countries. For future research, various additional instruments, such as dynamic panel data analysis or generalized method of moments (GMM), can be engaged to discover basic regularities in generating innovation and economic growth.

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