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Exploring the Nexus between Innovation and Economic Growth. Empirical Evidence from European Countries

Abstract. *This study investigates the relationship between economic growth, as measured by GDP per capita, and various innovation indicators across 24 European countries. Employing the PMG-ARDL model, the research examines both short-run and long-run interactions between GDP per capita and innovation inputs, including research and development expenditure (RDEXP) and the number of researchers in R&D (RRD), as well as outputs such as patent and trademark applications. The results demonstrate that while innovation significantly influences economic growth, the impact differs according to the type of innovation and the specific economic context of each country. The results of Dumitrescu Hurlin Panel Causality Test show bidirectional causality between GDP and resident patents and trademarks, indicating a mutually reinforcing relationship. A unidirectional causality from GDP to non-resident patents, trademarks, R&D expenditure, and researchers is observed, suggesting that economic growth primarily drives the attraction of foreign innovation and R&D investments, rather than being driven by them.*

Keywords: *economic growth, innovation, cointegration, ARDL, causality.*

JEL Classification: O32, O36, O40.

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1. Introduction

The development of innovation activities and their link to economic growth is a subject that has aroused the interest of both researchers and policymakers. However, in the literature, there is no consensus on the directional causality and influence between innovation and economic growth. Evidence was found regarding the impact of innovation activities on economic growth through increased efficiency, increased competitiveness, the creation of new industries and jobs, the creation and improvement of products and services, etc. On the other hand, there is also evidence that economic growth can create favourable conditions for the development and intensification of innovation activities. Going further, the possibility of the existence of a feedback-type relationship is also considered, as well as the situation of neutrality, of independence between innovation activities and economic growth.

The objective of our study is to investigate the short- and long-run relationship, as well as the unidirectional and bidirectional causality, between innovation and economic growth. The novelty of our approach consists of using the PMG-ARDL model and the pairwise Dumitrescu Hurlin Panel Causality Test to capture the complex relationship between economic growth and both input and output innovation indicators, for a panel of 24 European countries.

2. Theoretical foundations and literature review

The link between innovation and economic growth finds its foundations in Schumpeterian theories and the theory of endogenous technical change (Romer, 1990), (Grossman & Helpman, 1991), according to which, basically, innovative activities offer entrepreneurs the opportunity to produce at a temporary cost lower than that of its rivals, and, at the economic level, the scale of these innovative activities determines economic growth (Schumpeter, 1961), (King & Levine, 1993), (Aghion et al., 2005).

The link between innovation and economic growth can be direct, or indirect, through other macroeconomic factors (Hasan & Tucci, 2010), but the action can also be inverted, from other macroeconomic factors (implicitly, from economic growth) to innovation. In other words, there may be mutual causalities between innovation activities and economic growth, as well as feedback relationships between them. The literature finds four categories of relationships (hypotheses) between innovation and economic growth (Çetin, 2013), (Maradana et al., 2017):

- supply-leading hypothesis (SLH), unidirectional causality from innovation activities to economic growth;
- demand-following hypothesis (DFH), unidirectional causality from economic growth to innovation activities;
- feedback hypothesis (FBH), bidirectional causality between economic growth and innovation activities;
- neutrality hypothesis (NLH), independent relationship between economic growth and innovation activities.

[1] The main trend in the literature (supply-leading hypothesis, SLH) claims that innovation leads to economic growth (Çetin, 2013), (Segerstrom, 1991), (Guloglu & Tekin, 2012). Therefore, technological innovation is the main determinant of growth (Aghion et al., 2005), (Grossman & Helpman, 1991), innovation contributes to the creation and improvement of products, services, processes and business models, stimulating economic growth, and countries and regions that experience increased levels of technological innovation also have the fastest rates of economic growth, diversity and divergence. Innovation can come from the private or public sector, from large companies or small entrepreneurial firms, and can be an important objective of government policies. Schumpeter (1961) connects technological progress with an endless cycle of innovative firms that appear over time while technologically outdated, un-adapted firms disappear, also emphasising the role of public policies to encourage competition and innovation.

Numerous researchers insist in the necessity of a functional institutional framework to support the research and commercialisation of innovations, also taking into account sources of sectoral innovation market failure, on the role of public investments in infrastructure, to reduce regional differences (Fuentes, et al., 2021), but also of shifting the centre of interest of government policies towards private investments in R&D and innovation (Zayas-Márquez & Ávila-López, 2022), of the efficient interactions between the networks of public institutions and private companies for development and technological progress;

A second hypothesis states that economic growth can stimulate innovation, the so-called demand-following hypothesis (DFH) (Pradhan et al., 2018). Thus, it is considered that economic and institutional progress, education systems, and more efficient support mechanisms allow countries to invest more in research-development and innovation, as essential elements in strategies for economic growth and maintaining competitiveness at the global level (Pradhan et al., 2016). Economic growth enhanced expansion on foreign markets, stirs specialisation in performing sectors, based on research and development, simultaneously with the restructuring and adaptation of the production and innovation structures of countries (Pradhan et al., 2018), (Howells, 2005);

The third hypothesis (FBH), supports the possibility of the existence of both previous theories, through the so-called feedback effect (Guloglu & Tekin, 2012), (Çetin, 2013), (Pradhan et al., 2016), (Howells, 2005);

Finally, the last hypothesis proposes a situation of neutrality (NLH), the non-existence of causality, or an insignificant or unconvincing causal relation between innovation and economic growth (Çetin, 2013), (Pradhan et al., 2016), (Pradhan et al., 2018), (Sarangi et al., 2022).

Several scholars assert that these relationships are not found in economic reality in a ”pure” state, as researches over longer periods of time or within certain regions of the world indicate various results, inconstant over time. In other words, several hypotheses may be valid in different economic and temporal contexts. Guloglu & Tekin (2012) using the panel Granger-causality test show that the relationships between R&D and innovation, R&D and economic growth, as well as economic growth and innovation are all positive and significant in OECD economies. Sarangi et al. (2022) considering the case of G20 countries find that, in the vast majority of cases, the innovation-economic growth relationship is confirmed, being mostly a unidirectional causal relationship (either SLH or DFH). A somewhat surprising result is the lack of constancy of relationships, "all innovation variables seem to have caused economic growth differently, both in the long-run and short-run; and vice versa" (Sarangi et al., 2022, pp. 15-16).

Zayas-Márquez & Ávila-López (2022) address the relationship between innovation and economic growth by analysing the Granger causality in the case of two countries (Chile and Mexico) using data from 1996 to 2015. They find, in the case of Mexico, a bidirectional causality between innovation and economic growth per capita. In contrast, for Chile, they find a unidirectional causality from economic growth per capita to innovation.

Mohamed et al. (2022), analysing the impact of technological innovation on economic growth in several developing countries during 1990-2018, find that an increase in the indicators that explain technological innovation drive economic growth in the short and long term. Finally, several studies on countries such as Chile (Benavente, 2006) or Brazil (Carvalho & de Avellar, 2017) do not find any positive or significant relationship between innovation and economic growth or between innovation and productivity performance. Moreover, the study of Correa (2012) on capital endowment, competition, and innovation, reveals a mixed and ”unstable” relationship – a direct relationship in certain periods and no relationship in others.

3. Model description and Hypotheses

Based on the literature review, it is evident that innovation and economic growth have a reciprocal influence on each other throughout the development process. The inclusion of innovation as a determinant of economic growth, as well as economic growth as a determinant of innovation, in empirical research, is made easier by the clear and simple methods available for its measurement.

In this study, we utilise input and output innovation indicators to explore the relationship between innovation and economic growth.

To study the relationship between economic growth and innovation, this article uses annual data for the period 1997–2021 for a panel of 24 European countries for which statistical data were available. The variables were obtained from the World Bank (WB), World Intellectual Property Organisation (WIPO), UNESCO Institute for Statistics (UIS), and OECD National Accounts data files. To investigate the relationship between economic growth and innovation, we used GDP per capita (current US$) (GDP) as a variable for economic growth, while six different types of innovation indicators were used for innovation. The six innovation indicators considered in this study are: Patent applications residents (PAT), measured per million people; Patent applications non-residents (PATnon measured per million people; Trademark applications residents (TRAD); Trademark applications non-resident (TRADnon); Research and development expenditure (RDEXP), measured as a percentage of gross domestic product; Researchers in research and development activities (RRD), measured per million people. The study sample includes a panel of

24 European countries for which data were available for all six innovation indicators. Missing observation gaps were filled using a simple averaging or trend application. The statistical package Eviews 12.0 was used for the econometric analysis in this study.

First, descriptive statistics summarise GDP per capita and six innovation indicators—four outputs (PAT, PATnon, TRAD, TRADnon) and two inputs (RDEXP, RRD)—highlighting central tendencies and data distribution properties. The next step involves testing the stationarity of the variables using panel unit root tests like the Im, Pesaran, and Shin (IPS) test and the Phillips-Perron test, which help determine whether the variables are integrated of order zero I(0) or order one I(1), a necessary step to avoid spurious regressions due to non-stationarity (Dickey & Fuller, 1979). Once the order of integration is established, cointegration analysis is performed using tests such as those proposed by Pedroni and Kao to examine whether a long-run equilibrium relationship exists between GDP per capita and the innovation indicators, allowing for heterogeneity among cross-sections and determining if the non-stationary variables move together over time.

Given the potential mixed order of integration and the presence of cointegration, the Pooled Mean Group (PMG) estimation within the Auto-Regressive Distributed Lag (ARDL) framework is an appropriate econometric technique. The PMG-ARDL model allows for the estimation of both long-run and short-run dynamics simultaneously and is particularly suitable when the variables are I(0) and I(1) (Pesaran et al., 1999). The general form of the ARDL (1,1,1,1,1,1) model with GDP per capita as the dependent variable and the six innovation indicators (PAT, PATnon, TRAD, TRADnon, RDEXP, RRD) as independent variables can be expressed as:

$$GDP_{it} = \alpha_i + \lambda_i ECT_{it} + \sum_{k=1}^{p} \phi_{ij} GDP_{it-j} + \sum_{k=1}^{q} \beta_{ik} PAT_{it-k} + \sum_{k=1}^{q} \gamma_{ik} PATnon_{it-k} + \\ + \sum_{k=1}^{q} \delta_{ik} TRAD_{it-k} + \sum_{k=1}^{q} \eta_{ik} TRADnon_{it-k} + \sum_{k=1}^{q} \theta_{ik} RDEXP_{it-k} \\ + \sum_{k=1}^{q} \psi_{ik} RRD_{it-k} + \epsilon_{it} \quad (1)$$

where:

GDP_{it} - GDP per capita for country i at time t (dependent variable).

α_i - Country-specific fixed effects.

λ_i - Speed of adjustment coefficient, indicating how fast the variables return to equilibrium after a shock.

ECT_{it-1} - Error correction term from the long-run relationship.

ϕ_i - the coefficient of the lagged dependent variable

β_i - Short-run coefficients associated with the Patent applications by residents (independent variable).

γ_i - Short-run coefficients associated with the Patent applications by non-residents (independent variable).
δ_i - Short-run coefficients associated with the Trademark applications by residents (independent variable).
η_i - Short-run coefficients associated with the Trademark applications by non-residents (independent variable).
θ_i - Short-run coefficients associated with the Research and development expenditure as a percentage of GDP (independent variable).
δ_i - Short-run coefficients associated with the Researchers in R&D (per million people) (independent variable).
ψ_i - Short-run coefficients associated with the respective independent variables.
ϵ_{it} - Error term.

This model captures both the short-run dynamics (through the first differences of the variables) and the long-run relationship (through the error correction term) between economic growth and innovation. The pairwise Dumitrescu-Hurlin Panel Causality Test, developed by Dumitrescu and Hurlin (2012), is employed to evaluate causal relationships between variables within panel data frameworks.

Thus, the following hypotheses are formulated to explore the short-run and long-run relationships, as well as the unidirectional and bidirectional causality, between economic growth (GDP per capita) and both the output and input innovation indicators.

H1: There is a significant short-run relationship between economic growth and innovation output indicators (patent applications and trademark applications).
H2: There is a significant short-run relationship between economic growth and innovation input indicators (research and development expenditure and researchers in R&D).
H3: There is a significant long-run relationship between economic growth and innovation output indicators (patent applications and trademark applications).
H4: There is a significant long-run relationship between economic growth and innovation input indicators (research and development expenditure and researchers in R&D).
H5: There is a unidirectional causality from economic growth to innovation.
H6: There is a unidirectional causality from innovation to economic growth.
H7: There is bidirectional causality between economic growth and innovation indicators.

4. Data analysis

The descriptive statistics presented in Table 1, show significant differences in economic growth (measured by GDP per capita) and innovation indicators in the 24 countries studied. The mean of GDP per capita is substantially higher than the median, suggesting a distribution skewed by a few countries with high economic output, a pattern similarly observed in the patent and trademark application variables

(PAT, PATnon, TRAD, TRADnon). The high standard deviations across these variables indicate considerable variability, while the positive skewness and elevated kurtosis values suggest that most countries have lower values with a few outliers exerting a strong influence. The Jarque-Bera test confirms that most variables deviate from a normal distribution, highlighting the presence of skewness and heavy tails. This variability underscores the diverse levels of innovation and economic performance among the countries, suggesting that any analysis of the relationship between innovation and economic growth must account for these differences. Thus, given the different units of measurement among the variables, applying the natural logarithm is essential to normalise the data, thereby reducing skewness and allowing for a more consistent and comparable analysis across variables.

Table 1. Descriptive statistics

	GDP	PAT	PATnon	TRAD	TRADnon	RDEXP	RRD
Mean	490580.5	4222.222	1516.005	16052.76	5776.442	1.516979	3331.953
Median	28714.43	840	178.5	4077	4387.5	1.31804	2900.204
Std. Dev.	1411280	9993.372	3418.677	25544.78	4689.855	0.912039	1915.347
Skewness	3.615991	3.552617	3.225586	2.082385	2.424014	0.635554	0.712701
Kurtosis	12.44627	12.35423	11.31664	3.737093	12.98126	-0.68066	-0.3407
Jarque-Bera	167.726	1.702444	10.039	22.785	23.214	25.643	29.687
Probability	0.000	0.426	0.006	0.000	0.000	0.000	0.000
Observations	576	576	576	576	576	576	576

Source: Authors' contribution.

The ARDL/Bounds procedure, developed by Pesaran et al. (1999, 2001), offers significant advantages over traditional cointegration tests, particularly in its flexibility regarding the integration properties of the variables. Unlike conventional methods, the ARDL model can incorporate variables that are either integrated I(0), or I(1), without the need for them to be uniformly integrated. This adaptability makes the ARDL approach particularly well-suited for empirical analyses involving variables with mixed orders of integration.

Before applying the ARDL model, it is essential to determine whether a trend or a non-zero constant exists across all variables. The unit root tests were conducted using the Dickey-Fuller, Im, Pesaran, and Shin, and Phillips-Perron methodologies.

Table 2. Panel unit root test

	Im, Pesaran and Shin W-stat			Augmented Dickey-Fuller			Phillips-Perron		
	t-statistics (Prob.)			t-statistics (Prob.)			t-statistics (Prob.)		
	At level	Δ	I	At level	Δ	I	At level	Δ	I
GDP	-1.71 (0.05)	-7.29 (0.00)	I(1)	59.21 (0.13)	139.7 (0.00)	I(1)	101.68 (0.00)	-	I(0)
PAT	-0.12 (0.44)	-10.59 (0.00)	I(1)	49.99 (0.39)	203.3 (0.00)	I(1)	69.27 (0.02)	420.6 (0.00)	I(1)
PATnon	1.03	-9.66	I(1)	34.38	184.3	I(1)	33.13	374.1	I(1)

	Im, Pesaran and Shin W-stat			Augmented Dickey-Fuller			Phillips-Perron		
	t-statistics (Prob.)			t-statistics (Prob.)			t-statistics (Prob.)		
	At level	Δ	I	At level	Δ	I	At level	Δ	I
	(0.84)	(0.00)		(0.93)	(0.00)		(0.94)	(0.00)	
TRAD	-3.40 (0.00)	-	I(0)	96.96 (0.00)	-	I(0)	107.08 (0.00)	-	I(0)
TRADnon	1.44 (0.92)	-8.76 (0.00)	I(1)	37.66 (0.85)	167.7 (0.00)	I(1)	42.59 (0.69)	313.1 (0.00)	I(1)
RDEXP	-0.95 (0.16)	-9.13 (0.00)	I(1)	58.28 (0.14)	175.4 (0.00)	I(1)	47.48 (0.49)	308.6 (0.00)	I(1)
RRD	0.50 (0.69)	-8.50 (0.00)	I(1)	54.66 (0.23)	161.9 (0.00)	I(1)	65.04 (0.05)	303.3 (0.00)	I(1)

Note: Δ - the first difference operator. I – the order of integration.

Source: Authors' contribution.

The panel unit root tests (Table 2) demonstrate mixed stationarity properties for the variables analysed. GDP per capita is non-stationary at the level, as indicated by the Im-Pesaran-Shin (IPS) and Augmented Dickey-Fuller (ADF) tests, but become stationary after first differencing (I(1)). However, the Phillips-Perron (PP) test suggests that GDP is stationary at the level (I(0)). Most of the innovation variables, such as PAT, PATnon, TRADnon, RDEXP, and RRD, are non-stationary at the level but become stationary after first differencing (I(1)). TRAD, however, is stationary at the level (I(0)) across all tests. These findings confirm the mixed order of integration among the variables, supporting the use of an ARDL model to appropriately handle this mixture of I(0) and I(1) variables.

Table 3. Data cointegration analysis

Alternative hypothesis: common AR coefs. (within-dimension)

	Statistic	Prob.	Weighted Statistic	Weighted Prob.
Panel v-Statistic	-3.482729	0.9998	-4.580839	1.0000
Panel rho-Statistic	1.864641	0.9689	2.035227	0.9791
Panel PP-Statistic	-2.952192	0.0016	-2.287365	0.0111
Panel ADF-Statistic	-3.461887	0.0003	-3.504997	0.0002

Alternative hypothesis: individual AR coefs. (between-dimension)

	Statistic	Prob.
Group rho-Statistic	3.689566	0.9919
Group PP-Statistic	-3.523224	0.0002
Group ADF-Statistic	-4.454595	0.0000

Source: Authors' contribution.

In this analysis, the Pedroni (1999) test was conducted under the assumption of no deterministic trend. The results, as shown in Table 3, reveal that 6 out of the 11 test statistics are statistically significant, leading to the rejection of the null hypothesis of no cointegration. This provides robust evidence that the variables under consideration are cointegrated, indicating the existence of a long-run equilibrium relationship between GDP per capita and the innovation indicators.

5. PMG-ARDL model results and discussion

The following section details the long-run and short-run relationships between GDP per capita and innovation indicators across the 24 European countries examined. The analysis also explores the varying impacts of patents, trademarks, research and development expenditures, and the number of researchers on economic growth, along with the speed of adjustment toward long-run equilibrium, considering each country's developmental stage.

Table 4. PMG-ARDL (1,1,1,1,1,1) results

Variable	Coefficient	Std. Error	t-statistic	Prob.
Long-run Estimates				
PAT	-0.317120	0.063253	-5.013528	0.0000
PATnon	-0.100143	0.045059	-2.222472	0.0268
TRAD	-0.128836	0.040610	-3.172531	0.0016
TRADnon	1.010328	0.122800	8.227402	0.0000
RDEXP	0.871031	0.261967	3.324965	0.0010
RRD	0.750360	0.070696	10.61385	0.0000
Short-run Estimates				
$COINTEQ_{t-1}$	-0.011931	0.006445	-1.851342	0.0647
D(PAT)	0.029996	0.028424	1.055326	0.2919
D(PATnon)	0.000314	0.012219	0.025662	0.9795
D(TRAD)	0.066865	0.020002	3.342823	0.0009
D(TRADnon)	0.049551	0.014857	3.335220	0.0009
D(RDEXP)	-0.147751	0.037203	-3.971493	0.0001
D(RRD)	0.121832	0.037226	3.272734	0.0012

Source: Authors' contribution.

The PMG-ARDL (1,1,1,1,1,1) results in Table 4 highlight the long-run and short-run relationships between the variables. Among the short-run estimates, resident trademark applications (TRAD) and non-resident trademark applications (TRADnon) have positive and significant effects on GDP (0.066865 and 0.049551, respectively), reflecting their immediate positive impact on economic performance. The *H1 hypothesis* is partially confirmed. While resident trademark applications (TRAD) and non-resident trademark applications (TRADnon) show significant positive short-run effects on GDP, patent applications by residents (D(PAT)) and non-residents (D(PATnon)) do not show a significant short-run impact. In contrast, research and development expenditure (D(RDEXP)) has a significant negative short-run impact (-0.147751), indicating that the immediate costs may outweigh the short-run benefits, though it contributes positively in the long-run. Researchers in R&D (D(RRD)) show a positive and significant short-run impact (0.121832), consistent with their role in fostering innovation and economic growth. The *H2 hypothesis* is partially confirmed. Researchers in R&D show a significant positive short-run impact on GDP, but research and development expenditure has a significant negative short-run impact, indicating that immediate costs may outweigh the short-run benefits. In the long-run, the coefficients for patent applications by residents (PAT) and non-residents (PATnon) are both negative and significant (-0.317120 and -0.100143, respectively), indicating that an increase in patent applications is associated with a decrease in GDP per capita. Also, resident trademark applications (TRAD) have a negative long-run impact (-0.128836), whereas non-resident trademark applications (TRADnon) exhibit a strong positive effect on GDP (1.010328), suggesting that foreign innovation inputs contribute more positively to economic growth. The *H3 hypothesis is partially confirmed*. For input variables, both research and development expenditure (RDEXP) and researchers in R&D (RRD) have significant positive long-run coefficients (0.871031 and 0.750360, respectively), indicating their essential role in driving long-run economic growth. Thus, the *H4 hypothesis* is fully confirmed. The error correction term ($COINTEQ_{t-1}$) is -0.011931, but it is only marginally significant (p = 0.0647), suggesting a slow adjustment speed towards the long-run equilibrium. The significance of this coefficient in the ARDL model lies in its ability to capture the dynamic process by which the economy responds to short-run shocks and moves back to its long-run path. A slow adjustment speed, as indicated by the low value of the coefficient, suggests that any temporary disequilibrium between GDP and innovation indicators could persist for an extended period before the economy fully reverts to its long-run growth path.

Table 5. Cross-section of short-run coefficients

	Countries							
	AUT	**BG**	**CZ**	**DE**	**DK**	**ES**	**EST**	**FIN**
$COINTEQ_{t-1}$	0.001 (0.00)	-0.03 (0.00)	0.008 (0.00)	-0.029 (0.00)	0.011 (0.00)	-0.008 (0.00)	-0.011 (0.00)	-0.018 (0.00)
D(PAT)	-0.02 (0.00)	-0.009 (0.01)	0.060 (0.00)	0.405 (0.00)	-0.037 (0.00)	-0.071 (0.00)	0.009 (0.00)	-0.067 (0.00)
D(PATnon)	0.016 (0.00)	-0.024 (0.00)	-0.020 (0.00)	0.134 (0.00)	0.024 (0.00)	0.102 (0.00)	-0.026 (0.00)	0.012 (0.00)
D(TRAD)	0.175 (0.00)	-0.040 (0.00)	0.069 (0.00)	-0.055 (0.00)	0.143 (0.00)	0.036 (0.00)	0.216 (0.00)	0.094 (0.00)
D(TRADnon)	0.009 (0.02)	0.048 (0.00)	0.135 (0.00)	0.048 (0.00)	0.075 (0.00)	-0.007 (0.22)	0.081 (0.00)	0.163 (0.00)
D(RDEXP)	-0.40 (0.00)	-0.106 (0.00)	-0.090 (0.00)	-0.315 (0.00)	-0.031 (0.01)	-0.289 (0.00)	0.060 (0.00)	0.004 (0.75)
D(RRD)	0.555 (0.00)	0.184 (0.00)	0.211 (0.00)	0.325 (0.00)	0.016 (0.00)	0.263 (0.00)	0.041 (0.16)	-0.121 (0.00)
	Countries							
	FR	**GB**	**HU**	**IRL**	**ISL**	**LIT**	**LTV**	**MLT**
$COINTEQ_{t-1}$	-0.02 (0.00)	0.014 (0.00)	0.005 (0.00)	-0.144 (0.00)	0.006 (0.00)	-0.025 (0.00)	-0.045 (0.00)	0.080 (0.00)
D(PAT)	0.412 (0.00)	0.168 (0.00)	-0.181 (0.00)	-0.010 (0.00)	-0.003 (0.02)	-0.040 (0.00)	-0.001 (0.50)	0.008 (0.00)

D(PATnon)	0.014 (0.00)	-0.210 (0.00)	-0.005 (0.00)	0.039 (0.00)	0.010 (0.00)	0.011 (0.00)	0.003 (0.00)	0.005 (0.00)
D(TRAD)	-0.03 (0.00)	0.035 (0.00)	0.007 (0.00)	0.017 (0.00)	-0.018 (0.00)	0.189 (0.00)	0.037 (0.00)	-0.168 (0.00)
D(TRADnon)	0.012 (0.00)	0.045 (0.00)	0.069 (0.00)	-0.036 (0.00)	0.061 (0.00)	0.039 (0.00)	0.091 (0.00)	0.089 (0.00)
D(RDEXP)	-0.34 (0.00)	-0.389 (0.01)	-0.213 (0.00)	-0.593 (0.00)	-0.056 (0.00)	0.016 (0.17)	0.007 (0.43)	-0.050 (0.01)
D(RRD)	0.002 (0.91)	0.463 (0.00)	0.001 (0.80)	-0.179 (0.00)	-0.021 (0.16)	0.056 (0.01)	-0.009 (0.64)	0.123 (0.00)
	Countries							
	NOR	**PL**	**PRT**	**RO**	**SK**	**SLV**	**SWE**	**TUR**
$COINTEQ_{t-1}$	0.008 (0.00)	-0.007 (0.00)	-0.004 (0.00)	0.015 (0.00)	-0.020 (0.00)	-0.005 (0.00)	0.008 (0.00)	-0.068 (0.00)
D(PAT)	-0.03 (0.00)	0.159 (0.00)	0.040 (0.00)	-0.019 (0.00)	-0.005 (0.00)	-0.004 (0.00)	-0.129 (0.00)	0.094 (0.00)
D(PATnon)	0.025 (0.00)	-0.028 (0.00)	-0.002 (0.00)	-0.045 (0.00)	0.009 (0.06)	-0.022 (0.06)	-0.019 (0.00)	0.001 (0.01)
D(TRAD)	0.057 (0.00)	0.246 (0.00)	-0.002 (0.10)	0.132 (0.00)	0.086 (0.00)	0.171 (0.00)	0.120 (0.00)	0.088 (0.00)
D(TRADnon)	0.009 (0.00)	-0.097 (0.00)	0.137 (0.00)	-0.089 (0.00)	-0.013 (0.15)	0.004 (0.66)	0.124 (0.00)	0.190 (0.00)
D(RDEXP)	-0.13 (0.00)	0.069 (0.00)	-0.139 (0.00)	0.152 (0.00)	-0.009 (0.02)	-0.278 (0.00)	-0.115 (0.00)	-0.291 (0.00)
D(RRD)	0.079 (0.00)	0.344 (0.00)	0.075 (0.00)	-0.111 (0.00)	0.234 (0.00)	0.263 (0.00)	0.077 (0.00)	0.046 (0.01)

Source: Authors' contribution.

The data in Table 5 present the short-run coefficients for 24 European countries, showing how innovation indicators and GDP per capita interact across different national contexts. For instance, in highly developed countries like Germany (DE) and France (FR), the impact of patent applications by residents (D(PAT)) is positive (0.405 and 0.412, respectively), suggesting that innovation activities directly contribute to short-run economic growth. Conversely, in less developed countries such as Romania (RO) and Bulgaria (BG), the short-run impact of resident patents is negative (-0.019 and -0.009), indicating that these countries may face challenges in translating innovation efforts into immediate economic gains. Moreover, the short-run effects of research and development expenditure (D(RDEXP)) are negative in most countries, including Austria (AUT) and Spain (ES), indicating that the short-run costs of R&D might outweigh the immediate benefits, though these investments are essential for long-run growth. However, countries like Estonia (EST) and Poland (PL) show positive short-run impacts from R&D expenditure, suggesting that their innovation environments may be more conducive to rapid economic returns. The adjustment coefficients (COINTEQt-1) indicate varying speeds of adjustment towards long-run equilibrium, with countries like Ireland (IRL) showing a relatively high speed of adjustment (-0.144), whereas others, such as Austria (AUT), exhibit much slower adjustment (0.001). These results imply that policies aimed at enhancing the immediate economic impact of innovation should consider the specific developmental stage and innovation capacity of each country, focusing on creating an environment where innovation inputs can more quickly and effectively translate into economic growth.

Several causality tests are commonly employed in the literature, with the most notable being the Granger test and the Dumitrescu and Hurlin test. To investigate the direction of causality in our panel data, we will utilise the Dumitrescu and Hurlin test, as it allows us to account for cross-sectional dependence within the panel.

Table 6. Results of pairwise Dumitrescu Hurlin Panel Causality Test

H_0:	W-Stat.	Zbar-Stat.	Prob.	Conclusion
PAT does not homogeneously cause GDP	2.302	3.459	0.00	Bidirectional causality exists between GDP and PAT
GDP does not homogeneously cause PAT	4.231	9.034	0.00	
PATnon does not homogeneously cause GDP	1.115	0.030	0.97	GDP does homogenously cause PATnon
GDP does not homogeneously cause PATnon	4.763	10.57	0.00	
TRAD does not homogeneously cause GDP	1.845	2.138	0.03	Bidirectional causality exists between GDP and TRAD
GDP does not homogeneously cause TRAD	2.789	4.866	0.00	
TRADnon does not homogeneously cause GDP	1.222	0.337	0.73	GDP does homogenously cause TRADnon
GDP does not homogeneously cause TRADnon	8.959	22.695	0.00	
RDEXP does not homogeneously cause GDP	1.023	-0.236	0.81	GDP does homogenously cause RDEXP
GDP does not homogeneously cause RDEXP	4.374	9.445	0.00	
RRD does not homogeneously cause GDP	1.437	0.960	0.33	GDP does homogenously cause RRD
GDP does not homogeneously cause RRD	4.204	8.954	0.00	

Source: Authors' contribution.

The results presented in Table 6 show bidirectional causality between GDP and both resident patent applications (PAT) and resident trademark applications (TRAD), indicating a mutually reinforcing relationship where economic growth and domestic innovation activities stimulate each other. This dynamic suggests the presence of a positive feedback loop, particularly in more developed nations with well-established innovation ecosystems. Conversely, the test results demonstrate that GDP homogeneously causes non-resident patent applications (PATnon), non-resident trademark applications (TRADnon), research and development expenditure (RDEXP), and the number of researchers in R&D (RRD), without evidence of the reverse causality. This pattern implies that, in these countries, economic growth acts as a catalyst to attract foreign innovation and R&D investments, rather than these innovation inputs serving as primary drivers of growth. Thus, we can affirm that in countries where bidirectional causality is observed, efforts should focus on enhancing the synergies between innovation and economic growth. Meanwhile, in contexts where growth drives innovation, policies that leverage economic expansion to attract and sustain foreign innovation and R&D investments could be particularly beneficial. These findings underscore the importance of designing innovation policies that are attuned to the specific economic conditions and developmental stages of each country, ensuring that innovation both supports and is sustained by economic growth. The Dumitrescu Hurlin Panel Causality Test demonstrates that the relationship between GDP per capita and innovation indicators varies in different contexts. *H5: There is a unidirectional causality from economic growth to innovation* is partially confirmed, with unidirectional causality observed from GDP to non-resident patent and trademark applications, while bidirectional causality exists for resident patent and trademark applications. *H6: There is a unidirectional causality from innovation to economic growth* is not confirmed, as GDP drives R&D expenditure and the number of researchers without reverse causality. *H7: There is bidirectional causality between economic growth and innovation indicators* is partially confirmed, indicating that, while bidirectional causality exists for resident innovation indicators, it does not hold for non-resident indicators.

The findings reveal a differential impact between domestic and foreign innovation, with resident patent applications showing a negative long-run effect on GDP, while non-resident trademark applications exhibit a positive influence. This disparity suggests that domestic innovation may not be as efficiently harnessed for economic growth as foreign innovation inputs, possibly due to inefficiencies or barriers within local innovation systems.

The analysis also underscores the importance of balancing short-run and long-run considerations in innovation policy. While the negative short-run impact of research and development expenditure points to the potential costs of innovation investments in the short term, the positive long-run effect indicates that these investments are essential for achieving sustainable economic growth.

6. Conclusions and implications

The relationship between economic growth and innovation is complex and multifaceted, influencing and being influenced by a variety of factors within the economic ecosystem. The long-run analysis shows that domestic innovation, particularly patent applications by residents, has a negative impact on economic growth, while foreign innovation inputs, such as non-resident trademark applications, exert a significantly positive influence. This suggests that domestic innovation systems may face inefficiencies or barriers that limit their contribution to economic growth, underscoring the need for policymakers to strengthen local innovation ecosystems through improved intellectual property rights enforcement, better support for startups, and enhanced commercialisation of patents.

In countries like Germany and France, the positive short-run impact of resident patent applications on GDP highlights the immediate economic benefits of domestic innovation activities, whereas in less developed countries such as Romania and Bulgaria, the short-run impact of resident patents is negative, indicating challenges in translating innovation efforts into economic gains. Estonia and Poland, on the other hand, show positive short-run impacts of R&D expenditure, suggesting that their innovation environments may be more conducive to rapid economic returns.

The study also highlights the importance of sustained investment in research and development (R&D) for long-run economic growth. The positive coefficients for R&D expenditure and the number of researchers in R&D indicate that these inputs are vital for driving sustained economic performance. However, short-run analysis reveals that the immediate costs of R&D may outweigh the benefits, suggesting that, while such investments are essential for future growth, they require careful management to balance short-run economic pressures with long-run innovation goals.

The causality tests suggest varying dynamics between innovation and economic growth. These findings imply that innovation policies should be tailored to the specific developmental stage and economic context of each country, ensuring that both domestic and foreign innovation inputs are effectively leveraged to support sustainable economic growth.

The study’s emphasis on a narrow set of innovation indicators may miss other elements, such as digital innovation or sector-specific developments, potentially resulting in an incomplete perspective of innovation’s impact on economic growth. Additionally, the PMG-ARDL model, though effective in capturing long-run and short-run dynamics, assumes linearity, which might oversimplify the complex, potentially nonlinear interactions between innovation and economic growth at various stages of development. In future research, we aim to apply a NARDL model to examine the relationship between innovation and economic growth across European countries with varying levels of development. This approach will allow us to explore potential asymmetries in how positive and negative shocks to innovation indicators affect economic growth in different economic contexts. By distinguishing between these groups, the study could provide tailored insights into how innovation policies should be designed to effectively stimulate growth in countries at different stages of development.

The implications for economic policies suggested by the results of our research are structured in several layers. First, all countries, and especially those with weak results in the innovation-growth relationship, must develop vigorous policies to stimulate regional and sectoral expansion of innovation systems, of the actual results of innovation, to achieve additional and sustainable economic growth in the long term. Second, innovation does not generate economic growth simply because it is a goal of governments and benefits from direct funding and support measures. Innovation is supported upstream through organisational frameworks, through a reliable and well-distributed infrastructure, through good education, solid and efficient institutions, high-level of ICT facilities, venture capital funding, and genuine cooperation between universities, research institutions, and the private sector. Third, authorities can directly support innovation by supporting firms that are willing and able to innovate more, by funding public research, or by encouraging private investment in research and innovation. On the other hand, due to limited funds and the multitude of urgencies, governments must choose between these priorities and find a balance between improving the general environment for innovation and direct support for innovation, in a mix of policies adapted to the particularities and priorities of each country. Implicitly, these difficult choices will translate into different policies from one country to another, and probably generate different results from one country to another, over a longer time horizon.

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