R&D EXPENDITURE AND REGIONAL INNOVATION IN ITALY: EVIDENCE FROM A PANEL DATA ANALYSIS

Andrea Ciccarelli, Audrey De Dominicis, Greta Torquati

Abstract. This study investigates the relationship between Research and Development (R&D) expenditure and innovation across Italian regions, employing patent applications as a proxy for innovation output. The primary objective is to assess the extent to which different types of R&D expenditure — higher education, business, and public sector — contribute to regional innovation capacity, under the assumption that knowledge constitutes a fundamental driver of economic growth. The findings reveal that higher education R&D expenditure has a significant and positive long-term impact on patent production, while business and public R&D expenditures show no statistically significant effects. These results highlight the central role of universities in Italy's innovation system and suggest policy implications aimed at enhancing university-industry collaboration and improving the effectiveness of public R&D funding.

1. Introduction

Since the late 1980s, endogenous growth theories have emphasized the crucial role of Research and Development (R&D) expenditure as key drivers of economic growth (Romer, 1990; Aghion & Howitt, 1992; Grossman & Helpman, 1991). Within this framework, R&D is recognized not only as a source of innovation but also to accumulate technological capabilities and absorb existing knowledge (Islam, 2009). Numerous empirical studies have shown that countries and regions investing more in R&D tend to experience faster economic growth and enjoy higher levels of social welfare (OECD, 2007; Edquist, 2011).

However, not all R&D investments yield equivalent impact. Business R&D targets patentable innovation and commercialization, whereas public and university research primarily drives fundamental knowledge, human capital formation, and spillovers within evolving innovation models (Guerrero *et al*., 2015; Carayannis & Campbell, 2009). In the Italian context, this issue is particularly relevant due to significant territorial disparities and the strong presence of a public university system. Understanding the differentiated impact of R&D sources is thus essential to identifying the most effective levers to promote innovation at the regional level.

This study aims to empirically assess the impact of R&D expenditure on regional innovation performance in Italy. Innovation is measured by the number of patent applications, a widely used proxy in the literature (Bottazzi & Peri, 2003; De Rassenfosse *et al*., 2013). Despite being a common measure, patents capture only formalized and patentable aspects of technological knowledge and do not capture non-patentable forms of innovation, such as tacit knowledge, process improvements, or organizational innovations. However, as stated by Griliches (1998), patent statistics remains a relevant tool, owing to their wide availability, their ability to capture inventiveness, and their slowly changing standard. Results should thus be read as reflecting one important dimension of regional innovation.

The analysis employs a Panel Autoregressive Distributed Lag (ARDL) model estimated through the Pooled Mean Group (PMG) estimator, which allows for both short-run dynamics and long-run equilibrium relationships.

2. Literature review

The role of Research and Development (R&D) expenditure as a fundamental driver of technological innovation and sustained economic growth. Endogenous growth theories pioneered by Romer (1986, 1990) and Lucas (1988) place knowledge accumulation and human capital at the heart of growth dynamics, emphasizing the non-rival and cumulative nature of technological progress. Within this framework, R&D investment is the key input that fuels the discovery of new ideas, enhancing productivity and long-term economic performance (Aghion & Howitt, 1992, 1998; Jones, 1995).

Innovation is commonly proxied by patent counts. Despite capturing only formalized knowledge, patents remain the most reliable output indicators due to their traceability, territorial specificity, and suitability for international comparisons (Griliches, 1990; Archibugi, 1992). Patent-based measures have been critically examined in literature, recognizing both their merits and limitations (Hall & Harhoff, 2012). Elasticity analyses, based on the newly introduced worldwide count of priority patents, confirm a stable long-run association between R&D intensity and patent propensity (De Rassenfosse *et al*., 2013).

The literature delineates R&D expenditure into three principal components: business R&D (BRD), public R&D (PRD), and higher education R&D (HRD), each contributing differently to the innovation ecosystem. Business R&D is typically motivated by commercial objectives and serves as a crucial endogenous factor for economic growth (Wei *et al*., 2001).

The entrepreneurial role of universities is framed by the Triple and Quadruple Helix models, which highlight their function as intermediaries connecting science,

industry, and government (Etzkowitz, 2003; Guerrero *et al*., 2015; Perkmann *et al*., 2013). Universities not only conduct fundamental research but also engage in technology transfer, patent licensing, and spin-off creation, thereby amplifying knowledge spillovers and enhancing regional innovation capacity (Audretsch & Keilbach, 2011). Moreover, public–private collaboration policies have been found to strengthen the effectiveness of R&D investments, specifically by moderating knowledge flows and enhancing the transfer of university knowledge to firms (Azagra-Caro & Consoli, 2016; Bellucci & Pennacchio, 2015).

Empirical research has consistently demonstrated a positive and statistically significant relationship between R&D expenditure and innovation output across multiple levels of analysis, including national contexts (Porter & Stern, 2000) and regional systems (Bottazzi & Peri, 2003; Barra & Zotti, 2018). Cross-country and regional analyses confirm that corporate and university research significantly enhance patent output, driving innovation at the national (Furman & Hayes, 2004) and regional level (Buesa *et al*., 2006), while public R&D often shows more variable or context-dependent effects, underscoring the importance of efficient coordination and institutional design (Bilbao-Osorio & Rodríguez-Pose, 2004).

In Germany, firm cooperation with public research institutions has been shown to positively influence patenting activity, emphasizing the value of collaborative innovation networks (Fritsch & Franke, 2004). Broader European evidence also confirms the importance of R&D for innovation: analyses by Pegkas *et al*. (2020) show a positive relationship between R&D expenditure and innovation output across EU countries, and according to the European Patent Office (EPO, 2024), universities and public research organizations accounted for about 8% of European patent applications in 2023, with a steady increase among the most active academic institutions, especially in digital technologies and life sciences. Furthermore, Wolszczak-Derlacz (2025) demonstrates that institutional size, age, research orientation, and funding structure are the main determinants of university patenting and co-patenting performance, suggesting that targeted policies can foster higher patent output.

In the Italian context, Barra and Zotti (2018) show that while all three R&D components contribute significantly to regional innovation performance, the R&D investments from universities and the private sector benefit the regional innovation activities the most. They also highlight the strategic role of intermediation structures, such as university technology transfer offices. However, the Italian innovation system faces specific challenges, including the predominance of SMEs, relatively low private R&D intensity, and fragmentation within public research, which limit the conversion of R&D expenditure into patentable innovations (Sterlacchini, 2008; Malerba *et al*., 1999; Evangelista & Vezzani, 2010). Recent studies further highlight the strategic role of universities as central actors in innovation systems, both through

direct patent production and via collaboration with private firms. For instance, Rusciano (2024), analyzing the "third mission" in Italian universities, shows how university–industry collaborations can amplify technology transfer capacity and improve the quality and impact of patents.

There are structural reasons to expect a stronger impact of HRD on patenting compared to other forms of R&D. The Italian university system is predominantly public and centrally governed, with evaluation frameworks (e.g., ANVUR, VQR) that promote third mission objectives. Many universities have Technology Transfer Offices (TTOs), incubators, and consortia that foster the translation of research into intellectual property (Perkmann *et al*., 2013; Abramo & D'Angelo, 2022). In contrast, public R&D is often aimed at broad goals, while business R&D is fragmented across SMEs with limited resources for patenting or a preference for informal protection strategies (Bugamelli *et al*., 2018). These features help explain the greater empirical significance of HRD in regional patent output.

3. Data and methodology

The empirical analysis is based on a panel data comprising the 20 Italian regions over the period 1995-2022. The variables were derived from the EUROSTAT and the Ministry of Enterprise and Made in Italy[1]. The aim of this study is to assess the impact of the different components of Research and Development (R&D) expenditure on innovative activity. This is measured through the annual number of patent applications (PAT), recognised as an established proxy for quantifying technological innovation in regional studies of knowledge spillovers (Bottazzi & Peri, 2003) and innovation system efficiency (Barra & Zotti, 2018). The explanatory variables considered include R&D expenditure of the business (BRD), public sector (PRD) and Higher Education (HRD).

Initially, unit root tests were employed to examine the order of integration of the variables in the panel dataset. Different unit root tests were estimated, according to Im *et al*. (2003), Dickey and Fuller (1979, 1981) and Phillips and Perron (1988), to test the hypothesis that each panel data series has a common unit root process.

Table 1 shows the results of panel unit roots tests for each variable, first in levels and next in first differences.

---

[1] Data are available in:
https://ec.europa.eu/eurostat/databrowser/view/rd_e_gerdreg/default/table?lang=en&category=scitech
.rd.rd_e for Eurostat data; https://www.uibm.gov.it/bancadati/single_search/text_search/index/ for Ministry of Enterprise and Made in Italy data.

Table 1 − *Panel unit roots tests.*

Variables		Stationarity tests					
		Im, Pesaran and Shin W-test		ADF-Fisher test		PP-Fisher test	
PAT	Level	-4.0927	***	116.2672	***	142.0158	***
	First difference	-9.8124	***	339.6962	***	569.0605	***
BRD	Level	1.1284		10.2161		9.6490	
	First difference	-3.5090		116.8009	***	293.5381	***
PRD	Level	2.3200		17.8998		49.5938	
	First difference	-5.7731	***	194.1608	***	49.5938	
HRD	Level	-0.0231		44.3347		47.0223	
	First difference	-2.8028	***	143.9037	***	47.0223	

Source: Authors' elaboration
Notes: Selection of lags based on Akaike information criterion (AIC); Newey and West (1994) bandwidth selection unisg Bartlett kernel; Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution; All other tests assume asymptotic normality; H_0: Unit root (assumes individual unit root process).
*** Significant at 1% level

The null hypothesis of a unit root is not rejected for the explanatory variables in levels. On the contrary, all tests reject the null hypothesis when applied to the first differences, for each variable. Based on these combined results, the series appear to be non-stationary in levels and become stationary after first-order differencing. Therefore, it is concluded that each explanatory variable is integrated of order one, i.e., I(1). In contrast, the dependent variable (PAT) is stationary in levels, and thus classified as I(0).

To assess the existence of a long-run relationship among the variables, we implement the cointegration test proposed by Westerlund (2007). Unlike residual based approaches, Westerlund's procedure directly tests for the presence of an error correction mechanism and is particularly robust in the presence of cross-sectional heterogeneity and dependence—features that characterise our regional panel.

Table 2 reports the results, confirming the existence of a long-run relationship between the dependent and explanatory variables.

Table 2 − *Cointegration test.*

Westerlund test for cointegration	Value
Group-t statistics	-2.9675***
Panel-t statistics	-1.7743**

Source: Authors' elaboration.
Note: ***, ** indicate rejection of the null hypothesis of no co-integration at 1% and 5% level of significance, respectively.

The confirmation of a long-run equilibrium relationship among the variables, as indicated by the Westerlund cointegration test, provides a sound econometric justification for estimating a Panel ARDL model in its error-correction form. To this end, a Panel ARDL (1,1,1,1) specification is estimated using the Pooled Mean Group (PMG) estimator developed by Pesaran *et al.* (1999).

The PMG estimator is particularly well-suited for this empirical context, as it allows for the joint modelling of short and long-run dynamics in panel data settings with a mixture of I(0) and I(1) variables, provided that none of the series is integrated of order two (I(2)). Although the dependent variable is stationary in levels (I(0)), the use of Westerlund's (2007) test remains appropriate in the presence of I(1) regressors, to assess whether a long-run equilibrium relationship exists driven by persistent dynamics in the independent variables.

A further advantage of the PMG estimator lies in its ability to accommodate regional heterogeneity in the short-run coefficients and adjustment speeds, while simultaneously imposing homogeneity in the long-run coefficients across regions.

This assumption is particularly appropriate in the case of Italian regions, which—despite exhibiting structural and economic differences—operate under a common institutional, legal, and policy framework that may generate similar long-run innovation dynamics.

The estimated model is expressed in an error-correction representation, capturing both the transitory responses of patenting activity to changes in R&D expenditure and the speed at which deviations from the long-run equilibrium are corrected.

The model is specified as follows:

$$\Delta pat_{i,t} = \phi EC_{i,t} + \beta_{i,1}\Delta BRD_{i,t} + \beta_{i,2}\Delta PRD_{i,t} + \beta_{i,3}\Delta HRD_{i,t} + \lambda_i \Delta PAT_{i,t-1} + \epsilon_{i,t} \tag{1}$$

$$EC_{i,t} = pat_{i,t-1} - \theta_1 BRD_{i,t-1} - \theta_2 PRD_{i,t-1} - \theta_3 HRD_{i,t-1} \tag{2}$$

Where:

$\Delta pat_{i,t}$ represents the annual change in patent applications in region *i* at time *t*, that is, the first difference of the variable *pat*.

$EC_{i,t}$ is the error correction term for region *i* at time *t*, which measures the deviation from the long-run equilibrium.

ϕ_i is the speed of adjustment coefficient toward the long-run equilibrium in region *i*; it is expected that $\phi_i < 0$ to ensure model stability (confirming cointegration).

$\beta_{i,j}$ are the short-run coefficients associated with the changes in the explanatory variables in region *i*, with *j*=1,2,3 corresponding to BRD, PRD, e HRD.

λ_i is the autoregressive coefficient of the lagged difference of the dependent variable in region *i,* capturing short-run dynamic dependence.

This error correction specification allows us to capture both the short-run dynamics — i.e., the immediate responses of innovation (patent applications) to changes in R&D spending – and the long-run equilibrium relationship between innovation and its structural determinants.

The model also quantifies the speed at which regional innovation converges back to its long-run equilibrium following a shock, offering valuable insights into the dynamic stability and temporal persistence of innovation responses.

4. Preliminary results

Table 3 reports the PMG estimates of the Panel ARDL model. The long-run coefficient associated with university R&D expenditure is positive (0.8866) and highly significant ($p<0.01$): a 1% increase in HRD translate, ceteris paribus, into a 0.88% rise in patent applications. This finding underscores the pivotal role of universities as generators of fundamental knowledge, providers of skilled human capital, and key nodes in technology transfer processes through dedicated structures such as incubators and spin-offs.

Table 3 − *Full Panel ARDL Estimation.*

	Pooled Mean Group Estimator	
	Coefficient	Standard Error
Variables	Long-Run Coefficients	
BRD	-0.025843	0.034408
PRD	0.123676	0.098231
HRD	0.886631***	0.063682
	Short-Run Coefficients	
COINTEQ01	-0.207576***	0.080136
D (BRD)	-0.016120	0.095018
D (PRD)	-0.003467	0.080812
D (HRD)	-0.186619	0.233631

Source: Authors' elaboration.
Note: All variables are expressed in natural logarithms to reduce heteroscedasticity and allow interpretation of the estimated coefficients as elasticities.

By contrast, the coefficients for business and public R&D expenditure are not statistically significant, indicating that these components do not exert a persistent impact on patent output. This outcome, although unexpected, is consistent with the literature. Italian firms, especially SMEs, show a low propensity to patent, often relying on informal protection strategies or incremental innovations (Sterlacchini, 2008; Evangelista & Vezzani, 2010; Lotti & Schivardi, 2005). Limited R&D budgets and ownership structures further constrain patenting (Giuri *et al.*, 2007), while regional disparities—particularly weaker innovation environments in the South—dilute the aggregate impact of BRD and PRD (Leogrande, 2024). This aligns with broader evidence of structural weaknesses in Italy's productivity and innovation system (Bugamelli *et al.*, 2018). For PRD, resources are often misaligned, being directed toward publications, infrastructure, or general programmes rather than patentable outcomes (Abramo & D'Angelo, 2009).

In the short run, none of the R&D components is significant, reflecting the long lags of innovation processes. Early studies (Hall, Griliches & Hausman, 1984; Griliches, 1990) and later work (Wang & Hagedoorn, 2014) show that the R&D–patent link unfolds gradually. In Italy, continuous R&D efforts are fragile and frequently interrupted (Bontempi *et al.*, 2024). Moreover, capitalization of R&D expenditures has been shown to anticipate future patenting, underscoring the forward-looking nature of R&D returns (Herb *et al.*, 2025). Overall, the short-run insignificance of BRD and PRD should not be seen as inefficacy, but as evidence of the slow and cumulative nature of innovation.

The error correction term (ECT = –0.2076; p < 0.01) is negative and significant, indicating that roughly 21% of deviations from the long-run equilibrium are corrected within one year. This confirms the presence of a stable adjustment mechanism and highlights the predominance of long-run effects of R&D on innovation.

5. Concluding remarks

Overall, the empirical evidence corroborates the hypothesis that only university R&D expenditure exerts a direct, positive, and lasting influence on regional patenting activity. This finding aligns with a broad strand of literature highlighting the unique capacity of academic institutions to produce fundamental knowledge, stimulate collaboration networks, and facilitate knowledge spillovers through structured mechanisms such as Technology Transfer Offices, incubators, and spin-offs. In contrast, public and private R&D spending—although substantial in absolute terms—appear less effective in translating into measurable innovation outputs unless complemented by more efficient allocation strategies and stronger links with the

local innovation ecosystem. Strengthening the connection between non-academic R&D actors and formal channels of technological valorisation may therefore be a critical step toward enhancing the overall productivity of research investments across regions.

Acknowledgements

References

ABRAMO G., D'ANGELO C. A. 2009. The alignment of public research supply and industry demand for effective technology transfer: the case of Italy. *Science and Public Policy,* Vol. 36, No. 1, pp. 2-14.

ABRAMO G., D'ANGELO C. A. 2022. Drivers of academic engagement in public–private research collaboration: An empirical study. *The Journal of Technology Transfer,* Vol. 47, No. 6, pp. 1861–1884.

AGHION P., HOWITT P. 1992. A model of growth through creative destruction, *Econometrica*, Vol. 60, No. 2, pp. 323-351.

AGHION P., HOWITT P. 1998. *Endogenous growth theory*. Cambridge, MA: MIT Press.

ARCHIBUGI D. 1992. Patenting as an indicator of technological innovation: A review, *Science and Public Policy*, Vol. 19, No. 6, pp. 357-368.

AUDRETSCH D.B., KEILBACH M. 2011. Knowledge spillover entrepreneurship, innovation and economic growth. In AUDRETSCH D.B., *ET AL.* (Eds.) *Handbook of Research on Innovation and Entrepreneurship*, Cheltenham: Edward Elgar, pp. 281-310.

AZAGRA-CARO J.M., CONSOLI D. 2016. Knowledge flows, the influence of national R&D structure and the moderating role of public-private cooperation, *The Journal of Technology Transfer,* Vol. 41, No. 1, pp. 152-172.

BARRA C., ZOTTI R. 2018. The contribution of university, private and public sector resources to Italian regional innovation system (in)efficiency, *The Journal of Technology Transfer*, Vol. 43, pp. 432-457.

BELLUCCI A., PENNACCHIO L. 2015. University knowledge and firm innovation: Evidence from European countries, *Journal of Technology Transfer*, Vol. 40, No. 6, pp. 795-815.

BILBAO-OSORIO B., RODRÍGUEZ-POSE A. 2004. From R&D to innovation and economic growth in the EU, *Growth and Change*, Vol. 35, No. 4, pp. 434-455.

BONTEMPI M. E., LAMBERTINI L., PARIGI B. M. 2024. Exploring the innovative effort: duration models and heterogeneity, *Eurasian Business Review*, Vol. 14, No. 13, pp. 587-656.

BOTTAZZI L., PERI G. 2003. Innovation and spillovers in regions: Evidence from European patent data, *European Economic Review*, Vol. 47, No. 4, pp. 687-710.

BUESA M., HEIJS J., PELLITERO M.M., BAUMERT T. 2006. Regional Systems of Innovation and the Knowledge Production Function: The Spanish Case, *Technovation*, Vol. 26, No. 4, pp. 463-472.

BUGAMELLI M., LOTTI F., AMICI M., *ET AL*. 2018. Productivity growth in Italy: A tale of a slow-motion change. *Bank of Italy Occasional Papers*, No. 422.

CARAYANNIS E.G., CAMPBELL D.F.J. 2009. 'Mode 3' and 'Quadruple Helix':Toward a 21st-century fractal-innovation ecosystem, *International Journal of Technology Management*, Vol. 46, No. 3-4, pp. 201-234.

DE RASSENFOSSE G., DERNIS H., GUELLEC D., PICCI L., *ET AL*. 2013. The worldwide count of priority patents: A new indicator of inventive activity, Research *Policy*, Vol. 42, No. 3, pp. 720-737.

DICKEY D.A., FULLER W.A. 1979. Distributions of the estimators for autoregressive time series with a unit root, Journal of the American Statistical Association, Vol. 74, No. 366, pp. 427–431.

DICKEY D.A., FULLER W.A. 1981. Likelihood ratio statistics for autoregressive time series with a unit root, Econometrica, Vol. 49, No. 4, pp. 1057–1072.

EDQUIST C. 2011. Design of innovation policy through diagnostic analysis: Identification of systemic problems (or failures), *Industrial and Corporate Change*, Vol. 20, No. 6, pp. 1725–1753.

EPO. 2024. Annual Review 2024. European Patent Office.

ETZKOWITZ H. 2003. Research groups as quasi-firms: The invention of the entrepreneurial university, *Research Policy*, Vol. 32, No. 1, pp. 109-121.

EVANGELISTA R., VEZZANI A. 2010. The economic impact of technological and organizational innovations, *Research Policy*, Vol. 39, No. 8, pp. 1198-1208.

FRITSCH M., FRANKE G. 2004. Innovation, regional knowledge spillovers and R&D cooperation, *Research Policy*, Vol. 33, No. 2, pp. 245–255.

FURMAN J.L., HAYES R. 2004. Catching up or standing still? National innovative productivity among 'follower' countries, 1978-1999, *Research Policy*, Vol. 33, No. 9, pp. 1329-1354.

GIURI P., MARIANI M., BRUSONI S., *ET AL.* 2007. Inventors and invention processes in Europe: Results from the PatVal-EU survey, *Research Policy,* Vol. 36, No. 8, pp. 1107–1127.

GRILICHES Z. 1990. Patent statistics as economic indicators: A survey, *Journal of Economic Literature*, Vol. 28, No. 4, pp. 1661-1707.

GRILICHES Z. 1998. Patent statistics as economic indicators: a survey. In *R&D and productivity: the econometric evidence* (pp. 287-343). University of Chicago Press.

GROSSMAN G.M., HELPMAN E. 1991. Quality ladders in the theory of growth, *The Review of Economic Studies*, Vol. 58, No. 1, pp. 43–61.

GUERRERO M., CUNNINGHAM J., URBANO D. 2015. Economic impact of entrepreneurial universities' activities: An exploratory study of the United Kingdom, *Research Policy*, Vol. 44, No. 3, pp. 748-764.

HALL B. H., GRILICHES Z., HAUSMAN J. A. 1984. Patents and R&D: Is there a lag?, *National Bureau of Economic Research*, NBER Working Paper, No. 1454.

HALL B.H., HARHOFF D. 2012. Recent research on the economics of patents, *Annual Review of Economics*, Vol. 4, pp. 541-565.

HERB W., LOTZE M., SCHULTZE, W., *ET AL.* 2025. Real effects of capitalized research and development expenditures: A leading indicator for future innovation performance?, *Review of Quantitative Finance and Accounting*, Vol. 64, pp. 417-473

IM K.S., PESARAN H., SHIN Y. 2003. Testing for unit roots in heterogeneous panels, *Journal of Econometrics*, Vol. 115, pp. 53-74.

ISLAM M.R. 2009. R&D intensity, technology transfer and absorptive capacity. Working Papers 13-09, Monash University, Department of Economics.

JONES C.I. 1995. R&D-based models of economic growth, *Journal of Political Economy*, Vol. 103, No. 4, pp. 759-784.

KIM Y.K., LEE K., PARK W.G., CHOO K. 2012. Appropriate intellectual property protection and economic growth, *Research Policy*, Vol. 41, No. 2, pp. 358-375.

LEOGRANDE A. 2024. The Propensity for Patenting in the Italian Regions, MPRA Paper 120553, *University Library of Munich*, Germany.

LOTTI F., SCHIVARDI F. 2005. Cross-country differences in patent propensity: A firm-level investigation, *Giornale degli Economisti e Annali di Economia*, *Bocconi University*, Vol. 64, No. 4, pp. 469-502.

LUCAS R.E. 1988. On the mechanics of economic development, *Journal of Monetary Economics*, Vol. 22, No. 1, pp. 3-42.

MALERBA F., NELSON R., ORSENIGO L., WINTER S.G. 1999. 'History-friendly' models of industry evolution: The computer industry, *Industrial and Corporate Change*, Vol. 8, No. 1, pp. 3-40.

NEWEY W.K., WEST K.D. 1994. Automatic lag selection in covariance matrix estimation, *Review of Economic Studies*, Vol. 61, No. 4, pp. 631–654.

OECD.2007. *Innovation and growth: Rationale for an innovation strategy*. pp. 3-29.

PEGKAS P., STAIKOURAS C., TSAMADIAS C. 2020. Does research and development expenditure impact innovation? Evidence from the European Union countries, *Journal of Policy Modeling*, Vol. 42, No. 5, pp. 1041–1055.

PERKMANN M., TARTARI V., MCKELVEY M., *ET AL.* 2013. Academic engagement and commercialisation: A review of the literature on university–industry relations, *Research Policy*, Vol. 42, No. 2, pp. 423-442.

PESARAN M.H., SHIN Y., SMITH R.P. 1999. Pooled Mean Group Estimation of Dynamic Heterogeneous Panels, Journal of the American Statistical Association, Vol. 94, No. 446, pp. 621–634.

PHILLIPS P.C., PERRON P. 1988. Testing for a unit root in time series regression, *Biometrika*, Vol. 75, pp. 335-346.

PORTER M.E., STERN S. 2000. Measuring the 'ideas' production function: Evidence from international patent output, *International Journal of Technology Management*, Vol. 20, No. 5-8, pp. 460-484.

ROMER P.M. 1986. Increasing returns and long-run growth, *Journal of Political Economy*, Vol. 94, No. 5, pp. 1002-1037.

ROMER P.M. 1990. Endogenous technical change, *Journal of Political Economy*, Vol. 98, No. 5, Part 2, pp. S71-S102.

RUSCIANO R. 2024. The strategic role of the third mission in universities: a concrete case study, *European Scientific Journal*, Vol. 20, No. 16, pp. 1–12.

STERLACCHINI A. 2008. R&D, higher education and regional growth: Uneven linkages among European regions, *Research Policy*, Vol. 37, No. 6-7, pp. 1096-1107.

WANG E., HAGEDOORN J. 2014. The lag structure of the relationship between patenting and R&D, *Research Policy*, Vol. 43, No. 8, pp. 1275–1285.

WEI Y., LIU X., SONG M., ROMILLY P. 2001. Endogenous innovation growth theory and regional income convergence in China, *Journal of International Development*, Vol. 13, No. 2, pp. 153-168.

WESTERLUND J. 2007. Testing for error correction in panel data, Oxford Bulletin of Economics and Statistics, Vol. 69, No. 6, pp. 709–748.

WOLSZCZAK-DERLACZ J. 2025. The determinants of European universities patenting and co-patenting with companies, *The Journal of Technology Transfer*, Vol. 50, pp. 620-636.

Andrea CICCARELLI, Università degli studi di Teramo, aciccarelli@unite.it
Audrey DE DOMINICIS, Università degli studi di Teramo, adedominicis@unite.it
Greta TORQUATI, Università degli studi di Teramo, gtorquati@unite.it