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The Effect of R&D Expenditure on Innovation in the Regions of Greece

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Περίληψη

Στόχος της παρούσης εργασίας είναι η εμπειρική διερεύνηση της σχέσης, καθώς και η εκτίμηση της επίδρασης των δαπανών σε Έρευνα & Ανάπτυξη (συνολικών, δημοσίων και ιδιωτικών) στην καινοτομία, στις 13 περιφέρειες της Ελλάδας, κατά τη χρονική περίοδο 1995-2015. Η εμπειρική ανάλυση εδράζεται σε ενδογενή προσέγγιση (Grossman & Helpman, 1991; Jones, 1995b) και εφαρμόζει ανάλυση πάνελ δεδομένων (panel data analysis).

Τα ευρήματα της μελέτης καταδεικνύουν ότι υφίσταται – μακροχρονίως – μονόδρομη αιτιώδης σχέση από την έρευνα & ανάπτυξη στην καινοτομία και ότι οι επιδράσεις των συνολικών, των δημόσιων και των ιδιωτικών δαπανών για έρευνα & ανάπτυξη επί της καινοτομίας υπήρξαν θετικές και στατιστικά σημαντικές.

Συνεπώς προτείνεται η αύξηση των δαπανών σε Έρευνα & Ανάπτυξη με τη θέσπιση ειδικών φορολογικών κινήτρων, με τη χρήση νέων χρηματοδοτικών σχημάτων, με την ενίσχυση – με κεφάλαια σποράς – νέων επιστημόνων με ελπιδοφόρες και καινοτόμες ιδέες, και με την αξιοποίηση ενός ποσοστού των κερδών του υπερταμείου αποκρατικοποιήσεων και αξιοποίησης περιουσίας. Επίσης προτείνεται η ισοβαρής, θεσμική και χρηματοδοτική συμμετοχή των περιφερειών της Ελλάδας στον εθνικό χάρτη έρευνας και ανάπτυξης, καινοτομίας και επιχειρηματικότητας.

Λέξεις κλειδιά: Έρευνα & Ανάπτυξη, Καινοτομία, Περιφέρειες, Panel Data Analysis.

Abstract

The aim of this paper is to empirically investigate the relationship and the impact of Research and Development (R&D) expenditures (total, public and private) on innovation, in the 13 regions of Greece during the period 1995-2015. Empirical analysis is based on an endogenous approach (Grossman & Helpman, 1991; Jones, 1995b) and implements panel data analysis.

The findings of the study show that there exists a long-term unidirectional causal relationship between R&D and innovation and that the impact of total, public and private R&D expenditure on innovation has been positive and statistically significant.

It is therefore proposed the increase of R&D expenditures by introducing special tax incentives, using new funding schemes, strengthening new researchers with promising and innovative ideas and using a percentage of the profits of the Hellenic Cooperation for Assets and Participations. It is also proposed the equally, institutional and financial participation of the regions of Greece in the national map of R&D, innovation and entrepreneurship.

Keywords: Research & Development, Innovation, Regions, Panel Data Analysis.

1. Introduction

Economics, to a greater scope and with greater intense after World War II, explores the relationships among education, Research & Development (R&D), innovation, entrepreneurship, productivity and economic growth, through neoclassical and endogenous approaches. In particular, since the 1960s, the role of human capital has been explored in the context of the neoclassical approach, and afterwards, in the context of the new endogenous theories, R&D and innovation proxies are incorporated and the relationships among them are examined. Also, the role of spending / investment, public and private, is assessed. The ability of an economy to innovate, create and integrate new knowledge, as well as producing better quality products and services, is closely linked to its mid-term and long-term productive and development potential, with empowering employment. Romer (1990), Grossman & Helpman, (1991) and Aghion & Howitt (1992), through the endogenous growth theories, support the important role of R&D and innovation in the productivity and economic growth. Empirical studies show that countries investing most in R&D are growing faster and more sustainable and achieve higher levels of social welfare compared to those that invest less. The most advanced economies of the world, as well as the European Union (EU) as an entity, especially after 2000, have upgraded the institutional and financial support of the public and private fields of R&D. Of course, total, public and private expenditures vary, both between countries and among regions. The treaties of Maastricht in 1992 and Amsterdam in 1996 support the sharp increase in the allocation of the resources to the structural funds in order to assist fundamentally peripheral regions. But the global economic crisis has led, since 2008, to a reduction in relative R&D expenditures and to an increase of the intense of inequalities in research and innovation. R&D activities produce new knowledge, while the development activity launches state-of-the-art or advanced products and processes (OECD, 2005). Grossman and Helpman (1991) argue that TFP depends not only on the size of R&D activity but it can also be raised by an increase in the R&D capital. Since 1990's, developed countries, worldwide, have been engaged in an innovation race, investing more resources in R&D. At the beginning of the 2000's, the European Union (EU) set itself the ambitious goal to raise overall R&D investment to 3% of GDP in a decade and become the most competitive and dynamic knowledge-based economy in the world (known as the Lisbon strategy). In this way, the EU tried to narrow the innovation gap with the more technologically advanced countries, such as USA, South Korea, Singapore and Japan (Ramzi, 2015). Many reforms were implemented, such as the establishment of an effective internal market, flow without restrictions for researchers, knowledge and technology, an improved education system, and a more productive innovation and research base. In 2010, the EU introduced the 'Innovation Union', a strategy to improve the conditions for research and innovation in Europe and to create an innovation-friendly environment that will enhance growth and create new jobs.

In Greece, during the period 1995-2007, there was an increase of R&D expenditure, both in the public and private sector. In parallel, during the same period, innovation, as estimated by the patent applications to the European Patent Organization (EPO), exhibited an upward trend (Voutsinas et. al., 2015). The upsurge of the total and public R&D capital during the period 1981-2007, contributed to the substantial increase of the total factor productivity (TFP) of the Greek economy (Voutsinas and Tsamadias, 2014). However, the economic crisis and the subsequent austerity fiscal measures applied have had a negative impact on R&D and innovation in recent years. The research takes place especially in public Greek universities and research centers, and barely in business. In addition, public R&D expenditures are throughout the years lower than the average of EU Member States, with private R&D expenditures to be even lower. These findings come together with international studies (Innovation Scoreboard of the European Commission, INSEAD Global Innovation Index, etc.). However, the quantity and quality of research is quite satisfactory. The competitiveness of Greek researchers is internationally satisfactory. Taking into account the resources invested in this field and the quality of scientific publications, which are a proxy in the evaluation of the research produced, it appears that Greek researchers are more efficient than other

European researchers (e.g. English, Germans, etc.) (National Documentation Centre, 2018). However, there is a lag in the transformation of research results into innovation.

Greece is divided into 13 regions. Since the mid-90s, the responsibilities of regional authorities have continuously been expanding. However, their responsibilities in economy, education, research and innovation, even if there was inter temporal widening, are still relatively limited.

The purpose of this paper is to empirically investigate the causal relationship between innovation and R&D expenditures (total, public and private) in the regions of Greece over the period 1995-2015. It estimates also the effect of R&D expenditures (total, public, private) on innovation. Furthermore, it examines whether private and public R&D expenditures yield different results in the innovation process and how much they differ in causing innovation. To the best of our knowledge this is the first study to investigate the aforementioned issues for Greece at the national level.

The structure of the rest of the paper is as follows: Section 2 presents a brief overview of the empirical literature. Section 3 describes the methodology, the theoretical background and presents the results of the empirical analysis. Finally, Section 4 contains the concluding remarks and policy implications.

2. Brief Review of Empirical Literature

In recent three decades there have been conducted numerous empirical studies based on the new growth theories about Human Capital, R&D, Innovation, TFP and Economic Growth. The number of researchers, R&D expenditures and patent are often used as proxies for R&D and innovation, mainly due to the availability of data. The majority of the empirical studies investigate the impact of human capital, R&D and innovation in economic growth. Most of the reviewed empirical studies that examine innovation and R&D carried out in both national level and in a group of countries. Many of them have found that the R&D capital, in other words the accumulation of the annual R&D expenditures, has a positive and - in most cases - significant stimulus on economic growth (Coe, Helpman and Hoffmaister, 2009; Teixeira and Fortuna, 2010) and that the R&D activity has a positive impact on innovation (Voutsinas et. al., 2015). Fagerberg et. al. (1997) conducted a study for 64 European regions (in Spain, Italy, West Germany, France), with a view to estimate the impact of R&D (proxied by the share of R&D employees in total employment) and migration in the regional economic growth from 1983 to 1989. They found that the richer countries benefit from R&D, while the less developed ones benefit from migration. Cappellen et. al. (1999) examined 106 EU regions over the period 1980 to 1994, using a similar framework as Fagerberg et. al. (1997) and the results obtained that GDP per capita is positively influenced by the intensity of R&D employment. Badinger and Tondl (2003) tested the contribution of human capital and innovation (patents) to the regional economic growth (Gross Value Added) for 128 EU regions over the period 1993-2000. They show that the intensity of patent applications per employee and the share of adults with tertiary education have a statistically significant impact on regional economic growth. Badinger and Tondl (2005) have researched the effect of human capital proxies by the share of higher educated population on value added growth using a Lucas (1988) type mode for 196 European NUTS II regions over the period 1985-1999. They found that the growth of EU regions depends on capital accumulation, an increase on human capital, innovation and international technology transfer. Crescenzi (2005) explored the impact of the intensity of R&D expenditures, R&D personnel, high-tech patents and labour force with tertiary education on GDP growth, among 25 EU regions, from 1995-2003, and found that innovation and education proxies are significant. Rodriguez-Pose and Crescenzi (2008) employ a panel framework (regions of 25 EU countries) over the period 1995-2003, from a set of GDP, the intensity of R&D expenditures, including the shares of population and labour force with tertiary education, the rate of involvement in life-long learning, long-term unemployment and the percentages of young people and agricultural employees. The results showed that both the R&D and the other variables are statistically significant and have positive impact in enhancing regional economic growth, suggesting that a high level of human capital is crucial for the EU growth. Sterlacchini (2008) examined the relationship between the regional economic growth of 12 EU countries and their knowledge and human capital endowments, during the period 1995-2002. The most effective proxies enhancing the regional growth were the share of population with tertiary education and the intensity of R&D expenditures. Capello and Lenzi (2013) showed that the capacity to turn knowledge and innovation into regional growth differs among the 262 NUTS II regions of the 27 EU members. They also showed that the maximum R&D investment is the right goal for a region that create knowledge, but it is not the right policy for regions that innovate by exploiting external knowledge, or for regions that imitate innovation processes.

3. Empirical Analysis

This section presents the methodology, model, variables, data, sources and the econometric analysis (stationarity tests, cointegration tests, panel VECM and Granger-causality tests). It also presents the results and a discussion on the findings.

3.1. Methodology and Model

The endogenous growth models that proposed in the early 1990s (Romer, 1990; Grossman & Helpman, 1991; Aghion & Howitt, 1992), link economic growth with technological progress and innovation. In these models, innovation depends on the previous level of knowledge and on the R&D expenditure according to the following relationship:

$$\dot{\mathrm{A}} = \lambda \cdot \mathrm{X}^{\sigma} \cdot \mathrm{A}^{\phi} \quad \textbf{(1)}$$

where $\dot{\mathrm{A}}$ is the change in the knowledge stock (A) which depends on the R&D factor (X) and on the existing stock of knowledge A and σ, φ parameters of the theoretical model.

According to Jones (1995b), we suppose that φ equals to zero, because while the economy has accumulated a large stock of knowledge, each new idea has only a small incremental impact on the stock of knowledge, thus the increase in the stock of technological knowledge (the innovation) depends only on the R&D expenditure. Under the aforementioned assumption, the previous equation is reduced into the following form:

$$\dot{\mathrm{A}} = \lambda \cdot \mathrm{X}^{\sigma} \quad \textbf{(2)}$$

Taking natural logarithms in both sides in equation (2) leads to the following one:

$$\log(\dot{\mathrm{A}}) = \log(\lambda) + \sigma \cdot \log(X) \quad \textbf{(3)}$$

Thus the logarithm of innovation (the change in the knowledge stock) is analogous to the logarithm of the R&D input.

The empirical analysis is based on the previous equation that links innovation to R&D expenditure:

$$\log(P_i^t) = a + \beta \cdot \log(X_i^t),$$

where $\log(P_i^t)$ is the natural logarithm of the annual number of patent applications to the EPO in region *i* and in year *t*, $\log(X_i^t)$ is the natural logarithm of R&D expenditure in region *i* and in year *t*, a is a constant and β stands for the elasticity.

In the following empirical analysis, the aforementioned relationship is examined for the following pairs of variables: i. the total patent applications and total R&D expenditure, ii. the total patent applications and public R&D expenditure, and iii. the total patent applications and private R&D expenditure.

3.2. Data and Sources

In order to investigate the relationship between patents and R&D expenditures (total, public and private), we employ a panel of 13 regions (NUTS II level) over the period 1995-2015. The annual data for innovation, as approached by the patent applications to the EPO in NUTS III region, was obtained from the Hellenic Industrial Property Organisation and then grouped by the researchers. The annual data for total, private and public sector R&D expenditures for the period under consideration were taken from the Eurostat statistics database.[2] It is noted that R&D expenditures measured in pps and expressed in constant 2010 prices, while the few gaps existed in the time series, filled out with the linear interpolation method in EViews. All variables are turned into logarithms; thus, elasticities can be determined.

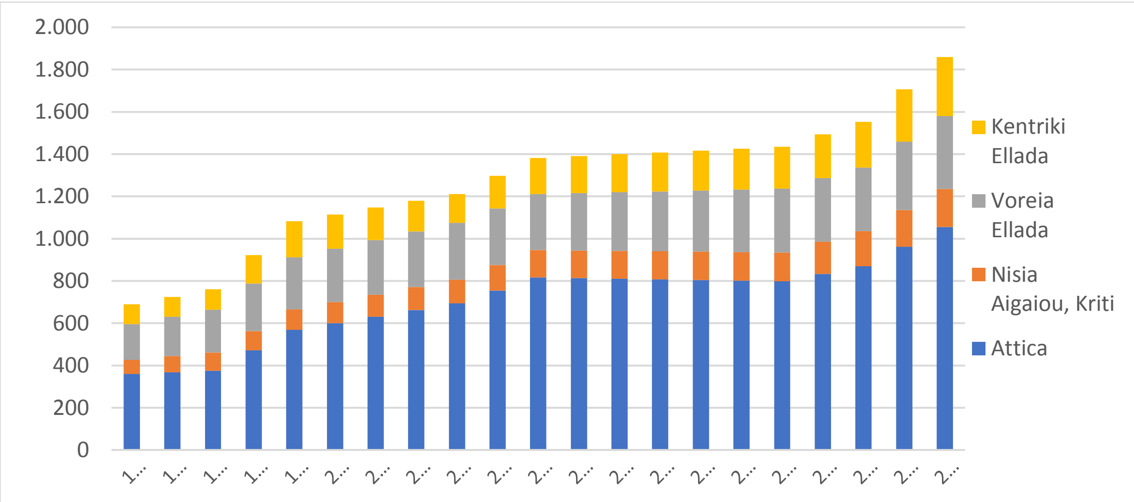

Figure 1: Total R&D Expenditures
Source: Eurostat, Notes: NUTS I classification.[3] R&D expenditures measured in pps and expressed in constant 2010 prices. (thousands of euros)

Figure 1 shows that total R&D expenditures increased significantly over the examined period (with fluctuations in their growth rates). In particular, Attica accumulates the greatest share of the R&D expenditures, with Northern Greece following, but their divergence is broadened throughout the years.

In addition, for 2015, the 56.8% of the total R&D expenditure of the country or EUR 1.06 billion is spent in the region of Attica, while the Central Macedonia region, with EUR 219.8 million, accounts for 11.8% of the total and the Region of Crete, with EUR 147.0 million, for 7.9%. This

[2] The production of R&D statistics for Greece is carried out by the National Documentation Center with the collaboration of the Greek Statistical Authority and afterwards those data was sent to Eurostat.
[3] The NUTS I classification for the groups of development regions is as follows: *Attica* (Attica), *Nisia Agaiou, Kriti* (North Aegean, South Aegean and Crete), *Voreia Ellada* (Eastern Macedonia and Thrace, Central Macedonia, Western Macedonia and Epirus) and *Kentriki Ellada* (Thessaly, Ionian Islands, Western Greece, Central Greece and Peloponnese).

happens due to the fact that most of the Universities and Technical Institutions of Greece are located in those three regions.

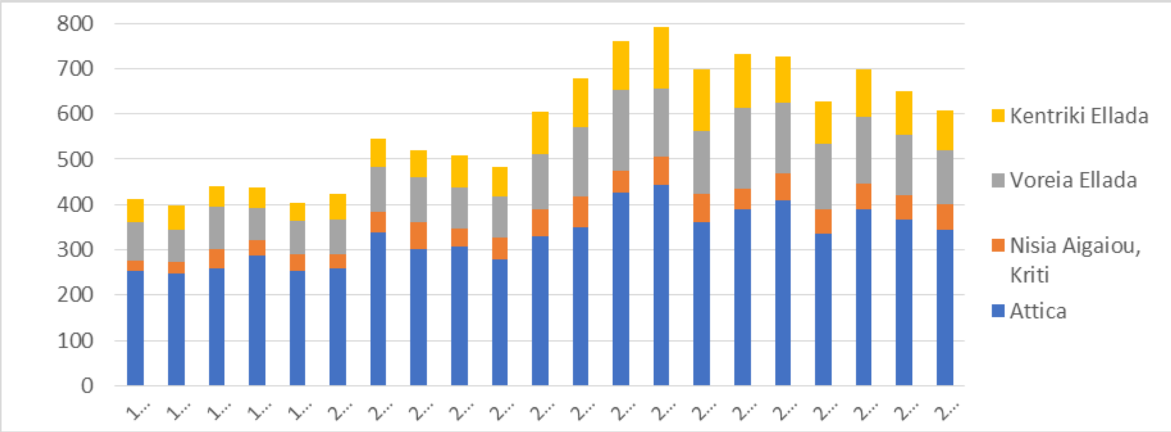

Figure 2: Total Patents
Source: Hellenic Industrial Property Organisation, Notes: NUTS I classification. Total Patents measured in absolute numbers

The total number of patent applications has increased significantly from 1995 to 2008, but since then a stabilization of the patents is observed, at the 2006 level. It is worth mentioned that most of the patent application (56.6%) arise from the region of Attica, which is the region that has the largest R&D expenditure.

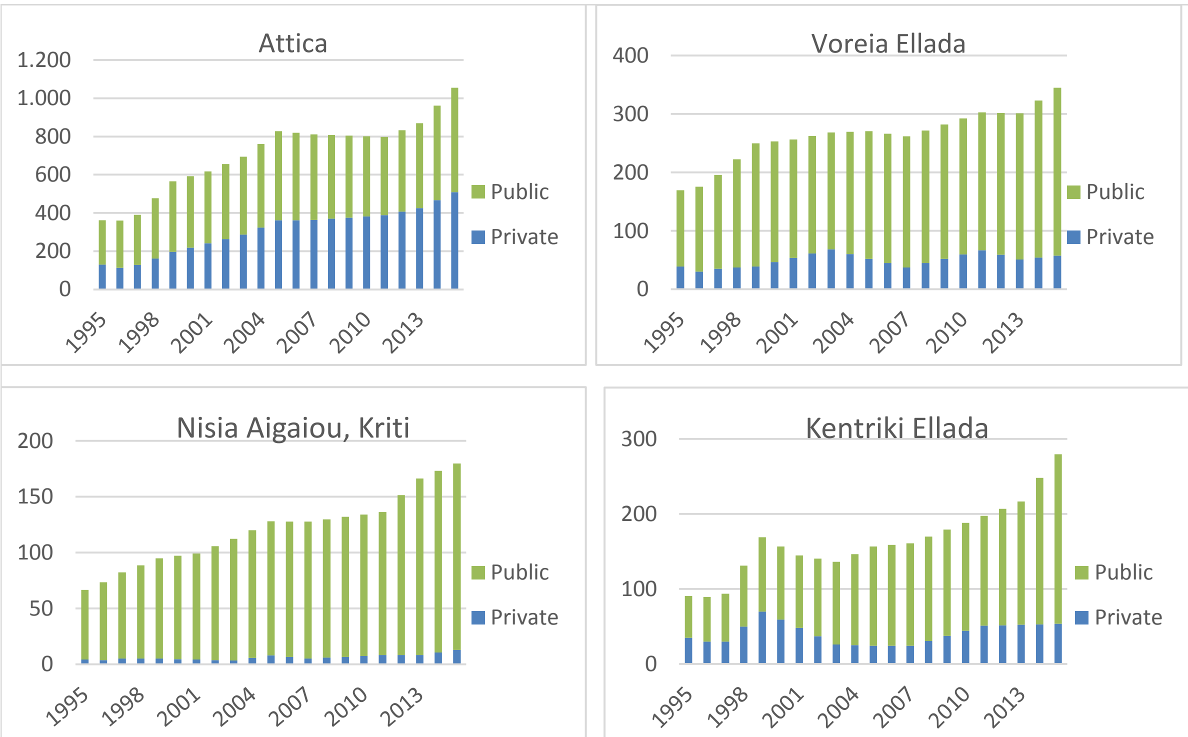

Figure 3: Public vs Private R&D Expenditures
Source: Eurostat, Notes: NUTS I classification. R&D expenditures measured in pps and expressed in constant 2010 prices. (thousands of euros)

As it can be inferred from the Figure 3, for all the Greek regions over the examined period, the public R&D expenditures are much higher than the private ones. Nevertheless, it is observed that the public and private R&D expenditures in the Attica region, over the last 7 years, beginning to be balanced. This is due to the existence of very small enterprises in Greece, which do not conduct R&D expenditures, as well as to the concentration of Universities in the large Attica and Kentriki Makedonia & Thraki regions.

3.3. Econometric Analysis

3.3.1 Stationarity tests

Initially, we examine the existence of unit root in levels and in first differences. The stationarity of the data is examined using Levin et. al. (2002), Augmented Dickey Fuller (1979, 1981) and Philips-Perron (1988).

Due to the fact that macroeconomic time series are trended and therefore in most cases are nonstationary, we difference the series successively until they become stationary and then use them for regression analysis. The variables of patents and R&D expenditures (total, public and private) are tested both in level and next in the first difference for each variable. The null hypothesis is the existence of unit root, the optimal lag length is selected using the Schwarz (1978) information criterion and the results are shown in Table 2.

Table 1: Panel Unit Root Tests

Variables		**LLC**	**ADF**	**PP**
lnP_{it}	Levels	0.911 (0.819)	8.846 (0.999)	10.651 (0.997)
	First Differences	-21.613*** (0.000)	302.439*** (0.000)	306.345*** (0.000)
$lnTR\&D_{it}$	Levels	6.382 (0.999)	1.302 (0.999)	0.995 (1.000)
	First Differences	-7.871*** (0.000)	115.591*** (0.000)	102.808*** (0.000)
$lnPUR\&D_{it}$	Levels	8.072 (0.999)	0.841 (1.000)	0.961 (1.000)
	First Differences	-8.453*** (0.000)	116.019*** (0.000)	101.810*** (0.000)
$lnPRR\&D_{it}$	Levels	3.383 (0.999)	9.678 (0.999)	8.988 (0.999)
	First Differences	-12.845*** (0.000)	191.378*** (0.000)	186.831*** (0.000)

Notes: The null hypothesis for the tests is that the panel has a unit root. p-values in parenthesis. ***, **, * indicates the rejection of the null hypothesis at 1%, 5% and 10% level of significance respectively. Bartlett spectral kernel, Newey-West (1994) bandwidth for all tests. Lag selection automatically via Schwarz (1978) info criterion.

lnP_{it}: the logarithm of the patent applications to the EPO in region *i* and in year *t*, $lnTR\&D_{it}$: the logarithm of the total R&D expenditures in region *i* and in year *t*, $lnPUR\&D_{it}$: the logarithm of the public R&D expenditures in region *i* and in year *t* and $lnPRR\&D_{it}$: the logarithm of the private R&D expenditures in region *i* and in year *t*.

As it can be inferred from the results shown in Table 1, all variables have unit root in their levels, while they are stationary or integrated of order one I(1) in their first difference at the 1% level of significance. A standard regression analysis on the basis of their levels would produce spurious results, unless the variables were cointegrated. These results allow us to test for cointegration among the variables in consideration.

3.3.2. Panel Cointegration Tests

Since we have concluded that all variables that are non-stationary in levels become stationary in first differences, therefore are integrated of order one in their levels, we pass to the next step, which is to check whether there is a long-run relationship between the variables of the model. The cointegration of the variables is examined through the heterogeneous panel cointegration tests by Pedroni (1999, 2004). All these cointegration techniques allow us to take into account the presence of heterogeneity in the estimated parameters and dynamics across regions. To determine the optimal lag length, the Schwarz (1978) info criterion is used and cointegration tests are run with heterogeneous trends.

We first perform panel cointegration tests that contain total R&D expenditures, afterwards private R&D expenditures and finally public R&D expenditures as a proxy for R&D. The results of Pedroni panel cointegration tests are presented in detail in Table 2 respectively and strongly suggest the hypothesis that there exists cointegration among the examined variables. Most of the statistics support the existence of cointegration relationship at 1%, 5% and 10% level of significance. The null of no cointegration is rejected by five to six out of seven tests at 1%, 5% and 10% probability level. The results from the tests that were described above support the hypothesis of a long run relationship between our variables in all regions and in all panels in Greece the examined period.

Table 2: Panel Cointegration Tests

Variables	**Panel A** **Total R&D expenditures**	**Panel B** **Public R&D expenditures**	**Panel C** **Private R&D expenditures**
		Pedroni Cointegration test	
Panel v	-0.851	-1.139	-1.731
Panel rho	-3.567***	-3.711***	-4.208***
Panel PP	-7.592***	-8.283***	-7.624***
Panel ADF	-6.782***	-6.581	-7.105***
Group rho	-1.209	-1.334*	-1.689**
Group PP	-9.309***	-10.867***	-8.466***
Group ADF	-5.071***	4.999***	-5.819***

***, ** and* indicate significant at 1%, 5% and 10% levels respectively. p-value are in parentheses. The null hypothesis for the tests is No Cointegration. ***, **, * indicates the rejection of the null hypothesis at1%, 5% and 10% level of significance respectively. Bartlett spectral kernel, Newey-West (1994) automatic bandwidth for all tests. Lag selection automatically via Schwarz (1978) info criterion.

3.3.3 Long Run Models Estimation with FMOLS

Given the presence of cointegration, we use the Fully-Modified OLS (FMOLS) technique developed by Pedroni (1996, 2000) for heterogeneous cointegrated panels, which controls for serial correlation of the errors and endogeneity of explanatory variables, in order to determine whether a long-run equilibrium relationship exists or not. The results from the tests are reported in Table 3 for all the proxies of R&D. Overall, three different panels are assessed for each level of R&D expenditures. All the coefficients related to R&D are positive and statistically significant at the 1% and 10% level respectively, where the coefficients can be interpreted as elasticity estimates.

Table 3: FMOLS Long Run Panel Tests

Variables	Panel A Total R&D expenditures	Panel B Public R&D expenditures	Panel C Private R&D expenditures
$lnTR\&D_{it}$	0.705*** (0.000)	-	-
$lnPUR\&D_{it}$	-	0.532*** (0.000)	-
$lnPRR\&D_{it}$	-	-	0.053* (0.084)
R^2	0.900	0.903	0.859
Adjusted R^2	0.895	0.898	0.852
Observations	260	260	260

The dependent variable is lnP_{it} (1995 to 2015). ***, ** and* indicate significant at 1%, 5% and 10% levels respectively. p-value are in parentheses.

According to our findings (Table 3) the coefficient of elasticity of innovation with regard to the total R&D expenditures is *0.71*. In addition, the coefficient of elasticity of innovation with regard to public and private R&D expenditures is *0.53* and *0.05* respectively, which means that a 1% increase in public and private R&D expenditures will foster innovation by 0.53% and 0.05% respectively. It is noted that the public R&D expenditures had a greater impact on innovation than private R&D expenditures.

3.3.4. Panel Error Correction Estimates

Given that the variables under study are cointegrated, a panel Vector Error Correction Model (VECM) is estimated to perform Granger (1988) causality tests. The findings for the endogeneity of the variables under consideration are reported in Table 4. The term ECT_{it-1} (equilibrium error term) is the one period lag residual of the model, while the lagged residuals from the cointegrating regression of FMOLS are included in the structure of the Granger causality test. ECT_{it-1} measures the rate by which the long-term disequilibrium in the dependent variable restores back to the equilibrium in the short-run.

The next step is to examine short-run and long-run Granger causality between patents and all the proxies of R&D. Although a long-run relationship among all variables exists, which suggests that there must be Granger causality in at least one direction, it does not indicate the direction of temporal causality between these variables. Consequently in this case, the F-statistic and the lagged ECT can only define the direction of the causality. The long-run causal effect is represented by the t-statistic on the coefficient of the lagged ECT_{it-1}, while the short-run causal relationship is represented by the F-statistic on the explanatory variables (Narayan and Smyth, 2006).

Since we have estimated the VECM for all variables of the model, we implement a Wald F-test to examine the significance of the short-run coefficients. The coefficients of the differenced variables and of the term ECT_{it-1} represent the short-run and long-run dynamic relationships between the variables, respectively.

Table 4: Panel VECM Causality Test Results

	Variables	Short-run dynamics non-causality		Weak exogeneity	Tests of Granger non-causality (joint short run dynamics and ECT)	
		DP_{it}	$DR\&D_{it}$	ECT	DP_{it} and ECT	$DR\&D_{it}$ and ECT
Total R&D expenditures	DP_{it}	-	0.78 (0.38)	-0.53*** [-7.54]	-	28.93*** (0.00)
	$DR\&D_{it}$	0.76 (0.38)	-	-0.24*** [-6.91]	24.35*** (0.00)	-
Public R&D expenditures	DP_{it}	-	0.09 (0.77)	-0.54*** [-7.58]	-	28.78*** (0.00)
	$DR\&D_{it}$	4.39** (0.04)	-	-0.16*** [-5.11]	15.46*** (0.00)	-
Private R&D expenditures	DP_{it}	-	0.03 (0.86)	-0.33*** [-5.96]	-	17.76*** (0.00)
	$DR\&D_{it}$	1.53 (0.22)	-	-0.44*** [-7.29]	27.52*** (0.00)	-

Notes: In the short-run dynamics, asterisks indicate the rejection of the null hypothesis that there is a short- run non-causal relationship between the two variables. ECT represents the coefficient of the error correction term. Probability values are in brackets and reported underneath the corresponding partial F-statistic and sum of the lagged coefficients and indicate the rejection of the null hypothesis that the estimated coefficient is equal to zero (weak exogeneity). In the tests for Granger non-causality and strong exogeneity, asterisks denote the rejection of the null hypothesis of Granger non-causality and strong exogeneity, respectively. The Wald test statistics reported are distributed as a chi-square distribution with degrees of freedom the number of restrictions.

Table 4 reports the results of the short-run and long-run Granger-causality tests for the proxies of R&D and it is ascertained that the ECT of all variables, has a negative and statistically significant sign. These results imply that all variables under consideration are not weakly exogenous and respond to deviation from long-run equilibrium given the 1% level of significance of their respective ECT_{it-1} for all panels.

In the long-run, a bidirectional Granger causality between patents and R&D expenditures exists in all panels. In the short-run, in panels A and C, the Wald test indicates that there is no Granger causality, while in panel B there is unidirectional causality from patents to public R&D expenditures. Empirical results show that there is a strong relationship between patents, and all the proxies of R&D expenditure in the sample of Greek regions.

4. Concluding remarks and policy recommendations

The purpose of this study is twofold: firstly, to empirically investigate the short-run and long-run causal relationship among patents and R&D expenditures (total, public and private) over the transition period 1995-2015 in the Greek regions, and secondly, to estimate the effect of each proxy of R&D expenditures on patents for all regions. It is based on the endogenous theory of economic growth (Grossman & Helpman, 1991; Jones, 1995b).

The results of our empirical analysis allow us to draw the following conclusions. Firstly, there is evidence of bidirectional long-run causality running from all proxies of R&D expenditures to patents. In addition, in terms of short-run relationship, there is a unidirectional causality running from patents to public R&D expenditures. Secondly, the elasticity of patents with respect to total, public and private R&D expenditures, is 0.71, 0.53 and 0.05 respectively. Therefore, public R&D expenditures have had higher contribution to innovation compared with the private ones, over the relevant transitional period.

It is therefore proposed to increase R&D expenses by introducing special tax incentives, using new funding schemes, strengthening new researchers with promising and innovative ideas and using a percentage of the profits of the Hellenic Corporation for Assets and Participations. It is also proposed the equally, institutional and financial participation of the regions of Greece in the national map of R&D, innovation and entrepreneurship.

It is crucial to improve the level of legal environment by strengthening the science and technology legislation and improving laws and regulations (i.e. Law on the Protection of Intellectual Property Rights etc.). In addition, it is important to optimize the incentive mechanism of the promotion system for local officials, encourage local governments to compete around the important indicators of R&D and innovation and build an innovative and competitive country.

In the future, if more latest data especially after 2017 is obtained, more accurate efficiency measurements and efficiency trend analyses will be possible. In addition, the path of government competitive behavior affecting the R&D investment or efficiency of local and neighboring regions needs to be further explored.

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