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Does innovation promote economic growth? Evidence from European countries

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Abstract

The paper examines the long-run relationship between innovation and per capita economic growth in the 19 European countries over the period 1989–2014. This study uses six different indicators of innovation: patents-residents, patents-non-residents, research and development expenditure, researchers in research and development activities, high-technology exports, and scientific and technical journal articles to examine this long-run relationship with per capita economic growth. Using cointegration technique, the study finds evidence of long-run relationship between innovation and per capita economic growth in most of the cases, typically with reference to the use of a particular innovation indicator. Using Granger causality test, the study finds the presence of both unidirectional and bidirectional causality between innovation and per capita economic growth. These results vary from country to country, depending upon the types of innovation indicators that we use in the empirical investigation process. Most importantly, the study finds that all these innovation indicators are considerably linked with per capita economic growth. This particular linkage is either supply-leading or demand-following in some occasions, while it is the occurrence of both in some other occasions. The policy implication of this study is that countries should recognize the differences in innovation and per capita economic growth in order to maintain sustainable development in these countries.

Keywords: Innovation, Per capita economic growth, Cointegration, Granger causality, European countries

JEL Classification: O43, O16, E44

Background

Why do some regions grow continuously for many years whereas others stagnate? Why do some regions grow faster than others? The theoretical breakthrough in answering these questions started by Solow (1956) and Romer (1990) has lost its momentum, leaving some important questions unanswered. Following the neoclassical growth and endogenous growth theories, technological advance is believed to be the major driver of economic growth, yet how exactly new knowledge translates into superior economic performance by regions was neither described by the growth theories nor found unequivocal empirical explanation. Empirical studies, lacking theoretical underpinnings, looked into networks (Wal and Boschma 2009), labour mobility (Almeida and Kogut 1999), and other potential facilitators of spillovers (Tsvetkova 2015).

In the recent years, both researchers and policymakers have increasingly paid attention to investigate the link between innovation, entrepreneurship, and regional outcomes (Galindo and Mendez-Picazo 2014; Grossman 2009; Howells 2005; Malerba and Brusoni 2007; Tsvetkova 2015; Wang et al. 2005). However, in this paper, we specifically[1] look into the linkage between innovation[2] and economic growth in the selected European countries. Innovation is considered as one of the key drivers of the economy (Andergassen et al. 2009; Bae and Yoo 2015; Mansfield 1972; Nadiri 1993; Romer 1986; Santacreu 2015; Solow 1956), particularly since the seminal work of Schumpeter[3] (1911). It affects the economy in multiple channels, such as economic growth, global competitiveness, financial systems, quality of life, infrastructure development, employment, trade openness, and hence, spawns high economic growth.[4] All these above studies mostly focus on the impact of innovation towards economic growth, indicating the supply-driven approach of innovation-growth nexus. But in reality, it is the economic growth that can also increase the level of innovation in the development process. That means there is a feasibility of bidirectional causality between innovation and economic growth (Pradhan et al. 2016). Hence, the main objective of this paper is to examine the bidirectional linkage between innovation and economic growth. In sum, we would like to assess the importance of innovation-economic growth linkage, by investigating whether the level of innovation has contributed to economic growth, or whether the extension of the innovation is simply a consequence of rapid economic growth.

In this paper, we utilize the Granger causality approach to examine the dynamics between innovation and economic growth for a sample of 19 European countries. The main contribution of the study is twofold. First, we specifically assess the importance of innovation activities on economic growth, by investigating whether the innovation activities have contributed to economic growth, or whether the expansion of innovation activities are simply a consequence of rapid economic growth. The Granger causality approach has been deployed to carry out this investigation.[5] Second, our data set is more recent and comprehensive (i.e. 1989–2014) in contrast to existing studies.

The rest of the paper is sketched as follows. The "Theoretical basis and literature review" section presents the theoretical basis and literature review. The "An outline of innovation in the European countries" section summarizes the status of innovation in the European countries. The "Proposed hypotheses, variables, data structure, and model" section describes the proposed hypothesis, variables, data, and model. The "Results and discussion" section presents the results and discussion. Finally, we summarize and conclude in the "Conclusion" section.

Theoretical basis and literature review

For linking the relationship between innovation activities and economic growth, we draw upon the basic theory of endogenous technical change developed by Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992). Our typical version of this theory contains innovation activities which allow a specific entrepreneur to produce one of many intermediate products at a cost temporarily lower than that of his rivals. The extent of innovative activities undertaken by society commands the rate of economic growth (see, for instance, Schumpeter (1912), King and Levine (1993), Ulku (2004), Aghion et al. (2005)).

Literature specifies that innovation activities contribute to economic growth, both directly and indirectly via other macroeconomic factors, see, for instance, Furman et al. (2002), Hassan and Tucci (2010). But it is possible that innovation activities are also equally affected by economic growth and other macroeconomic factors. That means, in practice, both innovation activities and economic growth can cause each other and therefore, there is the possibility of feedback relationship between the two. Previous studies on this issue, in general, can be categorized in four different forms (Cetin 2013; Pradhan et al. 2016), namely supply-leading hypothesis (SLH), demand-following hypothesis (DFH), feedback hypothesis (FBH), and neutrality hypothesis (NLH). The SLH shows unidirectional causality from innovation activities to economic growth (see, for instance, Pradhan et al. (2016), Cetin (2013) Guloglu and Tekin (2012), Fan (2011), Yang (2006)). The DFH reflects unidirectional causality from economic growth to innovation activities (see, for instance, Pradhan et al. (2016), Sadraoui et al. (2014), Cetin (2013), Sinha (2008), Howells (2005)). The FBH reveals the bidirectional causality between economic growth and innovation activities (see, for instance, Pradhan et al. (2016), Guloglu and Tekin (2012), Cetin (2013), Howells (2005)). Finally, the NLH displays the independent relationship between economic growth and innovation activities (see, for instance, Pradhan et al. (2016), Cetin (2013)). The aim of our study is to validate these four hypotheses in the selected European countries—a group of countries that has little attention in the literature.

An outline of innovation in the European countries

As cited above, innovation and economic growth cause each other in the development process (Agenor and Neanidis 2015; Aghion et al. 2010; Fan 2011). There are two ways we can address the innovation-growth issue: first, the regional disparities of innovation activities and economic growth in the European countries, and second, the causal link between innovation and economic growth in these countries. This paper deals with both issues. However, in this section, we address the disparity issue. Overall, innovation can be represented in multiple ways (see, for instance, Pradhan et al. (2016)). Nonetheless, we use six different types of innovation[6] in this paper. These include number of patents-residents (PAR), measured per thousand of population; number of patents-non-residents (PAN), measured per thousand of population; research and development expenditure (RDE), measured as a percentage of real gross domestic product; researchers in research and development activities (RRD), measured per thousand population; high-technology exports (HTE), measured as a percentage of real domestic product; and scientific and technical journal articles (STJ), measured per thousand population. The detailed descriptions of these six innovation indicators are available in Table 1.

Tables 2 and 3 provide the general status of innovation indicators in the European countries, both individually and as a group. The status of innovation (PAR, PAN, RDE, RRD, HTE, and STJ) in the European countries is noticed here during four different time periods from 1989 to 2014[7] (see, Tables 2 and 3). These four periods are P1: 1989–2000, P2: 2001–2007, P3: 2008–2014, and P4: 1989–2014. The salient points of this innovation status are as follows.

Table 1 Definition of variables

Variable code	Variable definition
GDP	Per capita economic growth: expansion of a country's economy, expressed in per capita gross domestic product.
PAR	Patents filed by residents: expressed in numbers per thousand population.
PAN	Patents filed by non-residents: expressed in numbers per thousand population.
RDE	Research and development expenditure: expressed as a percentage of real gross domestic product.
RRD	Researchers in research and development activities: expressed in numbers per thousand population.
HTE	High-technology exports: expressed as a percentage of real gross domestic product.
STJ	Scientific and technical journal articles: expressed in numbers per thousand population.

Variables above are defined in the *World Development Indicators of World Bank*

First, the status of patents-residents is relatively high in comparison to patents-non-residents. This is true for most of the European countries and for all the four time periods (P1–P4).

Second, the volume of patents-residents is relatively high in Germany, France, the UK, and Italy, while it is considerably low in Belgium, Czech Republic, Greece, and Portugal.

Third, the volume of patents-non-residents is considerably high in Germany, the UK, France, and Norway, while it is relatively low in Belgium, Greece, Portugal, and Romania.

Fourth, the level of research and development expenditure is legitimately high in Sweden, Finland, Germany, France, Denmark, and the Netherlands, while it is relatively low in Romania, Greece, Portugal, and Hungary.

Fifth, the level of researchers in research and development activities is fairly high in Finland, Norway, Denmark, Ireland, and Sweden, while it is fairly low in Italy, Poland, France, Germany, Spain, and Romania.

Sixth, the volume of high-technology exports is moderately high in Ireland, the Netherlands, the UK, Finland, and Belgium, while it is noticeably low in Hungary, Czech Republic, Poland, and Norway.

Seventh, the volume of scientific and technical journal articles is relatively high in Sweden, Finland, Denmark, the UK, and the Netherlands, while it is considerably low in Romania, Poland, Portugal, and Hungary.

The above observations are absolutely true for all the four time periods, i.e. P1 (1989–2000) to P4 (1989–2014). However, the overall trend has been increasing for all the innovation indicators.

Methods of Study

In this section, we empirically test the causality between innovation and per capita economic growth. Specifically, the causality between innovation and per capita economic growth can be addressed in four different ways: *supply-leading hypothesis* of innovation-growth nexus, *demand-following hypothesis* of innovation-growth nexus, *feedback hypothesis* of innovation-growth nexus, and *neutrality hypothesis* of innovation-growth nexus. These are all clearly elaborated in the literature review section.

Table 2 Trend of Innovation (per thousand population) in European countries

Countries	PAR				PAN				RDE			
	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
Austria	0.25	0.26	0.27	0.26	0.06	0.03	0.03	0.05	1.77	2.29	2.76	2.28
Belgium	0.07	0.05	0.06	0.06	0.04	0.02	0.01	0.03	1.87	1.90	2.12	1.95
Czech Republic	0.06	0.06	0.08	0.07	0.33	0.19	0.01	0.19	1.07	1.23	1.51	1.26
Denmark	0.25	0.32	0.27	0.28	0.14	0.03	0.03	0.08	1.99	2.49	2.99	2.53
Finland	0.44	0.38	0.32	0.39	0.38	0.04	0.02	0.20	2.93	3.43	3.77	3.38
France	0.22	0.22	0.22	0.22	0.06	0.05	0.03	0.05	2.18	2.15	2.23	2.18
Germany	0.48	0.59	0.58	0.54	0.11	0.14	0.16	0.13	2.32	2.51	2.83	2.55
Greece	0.02	0.04	0.06	0.04	0.02	0.01	0.01	0.01	0.53	0.58	0.68	0.59
Hungary	0.13	0.08	0.07	0.10	0.18	0.23	0.01	0.15	0.70	0.95	1.17	0.94
Ireland	0.23	0.21	0.14	0.20	0.35	0.02	0.01	0.18	1.22	1.19	1.64	1.33
Italy	0.13	0.16	0.14	0.15	0.01	0.01	0.01	0.15	1.02	1.11	1.25	1.13
Netherlands	0.14	0.13	0.15	0.14	0.04	0.03	0.02	0.03	1.96	1.89	1.92	1.91
Norway	0.26	0.25	0.23	0.25	1.04	1.08	0.32	0.88	1.63	1.59	1.67	1.62
Poland	0.08	0.06	0.09	0.08	0.06	0.09	0.01	0.05	0.66	0.57	0.74	0.64
Portugal	0.01	0.01	0.05	0.02	0.10	0.01	0.01	0.05	0.63	0.84	1.55	0.99
Romania	0.09	0.05	0.06	0.07	0.02	0.01	0.01	0.01	0.51	0.42	0.50	0.47
Spain	0.06	0.07	0.07	0.06	0.02	0.01	0.01	0.01	0.85	1.09	1.36	1.09
Sweden	0.43	0.33	0.24	0.35	0.10	0.06	0.03	0.07	3.52	3.70	3.50	3.59
United Kingdom	0.33	0.32	0.25	0.31	0.16	0.17	0.19	0.15	1.77	1.73	1.77	1.75
European panel[#]	3.68	3.59	3.35	3.59	3.22	2.23	0.93	2.47	1.49	1.66	1.93	1.80

PAR is number of patents by residents, PAN is number of patents by non-residents, and RDE is research and development expenditure. P1 is 1989–2000, P2 is 2001–2007, P3 is 2008–2014, and P4 is 1989–2014
[#]The figures are average of all 19 European countries

Figure 1 depicts the possible patterns of causal relations between innovation activities and economic growth. We intend to test the following two hypotheses[8]:

H^0_{1A}: *Innovation activities do not Granger-cause per capita economic growth.*

H^1_{1A}: *Innovation activities Granger-cause per capita economic growth.*

H^0_{1B}: *Per capita economic growth does not Granger-cause innovation activities.*

H^1_{1B}: *Per capita economic growth Granger-causes innovation activities.*

The importance of this study is twofold: (a) we use a large sample of countries, from the European Union, over a recent span of time, and (b) we use the sophisticated econometric tools—and certain empirical approaches that have not been taken in these literature—to answer questions concerning the nature of Granger causal relationship between innovation and per capita economic growth, both in the short-run and long-run.

The inclusion of innovation as a determinant of economic growth (and vice versa) in empirical research is its straightforward measurement. Researchers can use either the input measures such as research and development expenditure (Goel and Ram 1994; Griliches 1992; Griliches and Mairesse 1986; Mansfield 1972) or innovation outputs such as patents (Audretsch and Feldman 1996; Bayoumi et al. 1999; Coe and Helpman

Table 3 Trend of innovation (per thousand population) in European countries

Countries	RRD				HTE				STJ			
	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
Austria	0.29	0.41	0.51	0.45	24.7	49.1	48.7	36.9	0.43	0.57	0.59	0.50
Belgium	0.27	0.30	0.34	0.30	58.0	67.4	87.6	73.2	0.55	0.62	0.68	0.61
Czech Republic	0.12	0.19	0.27	0.19	0.88	2.56	4.79	2.84	0.23	0.30	0.39	0.30
Denmark	0.63	0.89	1.21	0.95	4.24	6.09	5.28	5.01	0.82	0.93	1.01	0.89
Finland	1.17	1.45	1.42	1.37	67.8	70.8	34.3	48.3	0.90	0.95	0.93	0.85
France	0.04	0.05	0.06	0.05	38.1	38.2	49.2	37.9	0.51	0.49	0.49	0.48
Germany	0.04	0.04	0.05	0.04	35.5	54.9	63.9	45.7	0.51	0.53	0.55	0.50
Greece	0.12	0.15	0.20	0.15	4.77	4.78	5.15	4.01	0.26	0.37	0.43	0.29
Hungary	0.11	0.15	0.21	0.16	0.57	0.24	0.64	0.44	0.19	0.24	0.24	0.22
Ireland	0.54	0.64	0.73	0.64	294.8	201.6	134.6	201.2	0.38	0.48	0.64	0.43
Italy	0.02	0.02	0.03	0.02	15.6	16.1	17.4	16.4	0.35	0.42	0.45	0.41
Netherlands	0.16	0.18	0.19	0.18	73.3	102.2	96.2	86.9	0.75	0.81	0.91	0.81
Norway	0.92	1.01	1.12	1.07	1.37	1.51	1.57	1.53	0.69	0.76	0.92	0.85
Poland	0.03	0.04	0.04	0.04	1.04	2.09	5.65	2.98	0.13	0.17	0.19	0.16
Portugal	0.14	0.20	0.41	0.24	8.51	15.5	10.4	11.9	0.14	0.27	0.40	0.26
Romania	0.05	0.04	0.04	0.05	4.70	3.22	6.10	4.59	0.04	0.04	0.07	0.05
Spain	0.04	0.05	0.06	0.05	11.3	10.5	11.8	11.1	0.34	0.41	0.47	0.41
Sweden	0.51	0.61	0.56	0.59	6.51	5.26	4.52	4.98	1.12	1.10	1.02	1.06
United Kingdom	0.04	0.06	0.06	0.06	68.9	60.1	34.7	54.1	0.80	0.76	0.74	0.77
European panel[#]	0.27	0.33	0.40	0.33	52.2	38.2	34.5	44.1	1.01	0.57	0.62	0.53

RRD is researchers in research and development activities, HTE is high-technology exports, and STJ is scientific and technical journal articles. P1 is 1989–2000, P2 is 2001–2007, P3 is 2008–2014, and P4 is 1989–2014

[#]The figures are average of all 19 European countries

1995; Griliches 1990; Kim and Lee 2015; Maurseth and Verspagen 2002; Pradhan et al. 2016; Stokey 1995; Wang et al. 2005). But in this study, we deploy both types of innovation indicators (input and output) to investigate the linkage between innovation and economic growth.

On the empirical front, we use two variables: per capita economic growth (variable: GDP[9]) and innovation (variable: INN[10]). Table 4 presents the descriptive statistics of these innovation variables, particularly with reference to PAR, PAN, RDE, RRD, HTE, and STJ.

We take the sample of 19 European countries[11] to investigate the validity of two hypotheses, namely $H_{1A,B}$ and $H_{2A,B}$. The empirical investigation follows annual data over the period 1989 to 2014 and was obtained from the *World Development Indicators* of the World Bank. The study deploys cointegration and Granger causality (Granger 1988; 1986) to validate the above two null hypotheses (H^0_{1A} and H^0_{1B}). We have six different cases to validate these two hypotheses, particularly with reference to six different indicators of innovation. Case 1 deals with GDP and PAR, case 2 deals with GDP and PAN, case 3 deals with GDP and RDE, case 4 deals with GDP and RRD, case 5 deals with GDP and HTE, and case 6 deals with GDP and STJ.

Following Holtz-Eakin et al. (1988), we use the succeeding regression models to notice the long-run and short-run causal relationship between innovation and per capita economic growth.

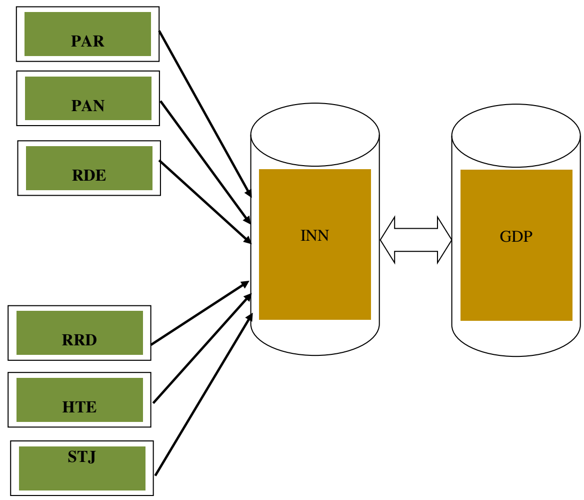

Fig. 1 Conceptual framework of the causality between innovation and per capita economic growth. Note 1: *GDP* is per capita economic growth and *INN* is innovation and used as a proxy for PAR, PAN, RDE, RRD, HTE, and STJ. Note 2: PAR is number of patents by residents, PAN is number of patents by non-residents, RDE is research and development expenditure, RRD is the researchers in research and development activities, HTE is the high-technology exports, and STJ is the scientific and technical journal articles

Table 4 Descriptive statistics of the variables

Countries	Variables					
	PAR	PAN	RDE	RRD	THE	STJ
Austria	−0.57/0.03	−1.44/0.07	0.38/0.06	−0.36/0.08	0.68/0.08	−0.24/0.02
Belgium	−1.27/0.05	−1.81/0.13	0.29/0.02	−0.51/0.03	0.85/0.07	−0.20/0.03
Czech Republic	−1.20/0.06	−0.10/0.73	0.08/0.06	−0.75/0.15	−0.69/0.30	−0.53/0.10
Denmark	−0.53/0.04	−1.50/0.08	0.40/0.07	−0.04/0.11	−0.25/0.06	−0.03/0.03
Finland	−0.41/0.07	−1.42/0.16	0.53/0.04	0.13/0.05	0.77/0.15	−0.03/0.01
France	−0.65/0.01	−1.35/0.14	0.34/0.01	−1.29/0.05	0.60/0.05	−0.31/0.01
Germany	−0.24/0.02	−0.86/0.05	0.40/0.03	−1.40/0.05	069/0.12	−0.28/0.02
Greece	−1.40/0.13	−2.57/0.18	−0.24/0.05	−0.85/0.11	−0.35/0.10	−0.47/0.12
Hungary	−1.14/0.04	−1.26/0.80	−0.04/0.09	−0.82/0.11	−1.32/0.25	−0.64/0.04
Ireland	−0.69/0.10	−1.67/0.19	0.11/0.06	−0.20/0.05	1.31/0.14	−0.32/0.10
Italy	−0.86/0.05	−1.74/0.12	0.06/0.05	−1.60/0.07	0.22/0.03	−0.38/0.05
Netherlands	−0.84/0.03	−1.54/0.15	0.28/0.02	−0.75/0.04	0.98/0.06	−0.08/0.03
Norway	−0.60/0.04	−0.15/0.35	0.21/0.02	0.01/0.03	−0.82/0.02	−0.10/0.10
Poland	−1.19/0.07	−1.40/0.57	−0.20/0.05	−1.40/0.03	−0.69/0.30	−0.79/0.08
Portugal	−1.79/0.31	−2.29/0.18	−0.05/0.16	−0.68/0.19	0.05/0.17	−0.62/0.19
Romania	−1.28/0.11	−2.14/0.49	−0.34/0.08	−1.35/0.06	−0.37/0.17	−1.31/0.11
Spain	−1.17/0.05	−2.10/0.18	0.03/0.09	−1.30/0.10	0.03/0.04	−0.40/0.06
Sweden	−0.51/0.12	−1.27/0.17	0.56/0.02	−0.24/0.04	−0.29/0.07	0.03/0.02
United Kingdom	−0.51/0.06	−0.82/0.10	0.24/0.01	−1.24/0.07	0.74/0.12	−0.12/0.01
European panel[#]	−0.89/0.42	−1.47/0.62	0.16/0.26	−0.79/0.53	0.13/0.74	−0.37/0.34

PAR is number of patents by residents, PAN is number of patents by non-residents, RDE is research and development expenditure, RRD is researchers in research and development activities, HTE is high-technology exports, STJ is scientific and technical journal articles, and GDP is per capita economic growth. Values reported here are natural logs of the variables
[#]The reported statistics are calculated at the panel level

Model 1: For individual country analysis

$$\Delta\text{GDP}_t = \alpha_1 + \sum_{k=1}^{p}\beta_{1k}\,\Delta\text{GDP}_{t-k} + \sum_{k=1}^{q}\lambda_{1k}\,\Delta\text{INN}_{t-k} + \delta_1\text{ECT}_{t-1} + \varepsilon_1 t \tag{1}$$

The testable hypotheses are:

$$H_0 : \lambda_{1k\,=\,0};\ \text{and}\ \delta_1 = 0 \quad \text{for}\ k = 1, 2, \ldots, q$$
$$H_A : \lambda_{1k\,\#\,0};\ \text{and}\ \delta_1 \# 0 \quad \text{for}\ k = 1, 2, \ldots, q$$

$$\Delta\text{INN}_t = \alpha_2 + \sum_{k=1}^{p}\beta_{2k}\,\Delta\text{INN}_{t-k} + \sum_{k=1}^{q}\lambda_{2k}\,\Delta\text{GDP}_{t-k} + \delta_2\text{ECT}_{t-1} + \varepsilon_2 t \tag{2}$$

The testable hypotheses are:

$$H_0 : \lambda_{2k\,=\,0};\ \text{and}\ \delta_2 = 0 \quad \text{for}\ k = 1, 2, \ldots, q$$
$$H_A : \lambda_{2k\,\#\,0};\ \text{and}\ \delta_2 \# 0 \quad \text{for}\ k = 1, 2, \ldots, q,$$

where ECT[12] is error correction term, which is derived from the long-run cointegration equation; p and q are the lag lengths for the estimation; Δ is the first difference operator; and ε_{1t} and ε_{2t} are the independent and normally distributed random error with a zero mean and a finite heterogeneous variance.

Model 2: For panel data analysis

$$\Delta\text{GDP}_{it} = \alpha_{3j} + \sum_{k=1}^{p}\beta_{3ik}\,\Delta\text{GDP}_{it-k} + \sum_{k=1}^{q}\lambda_{3ik}\,\Delta\text{INN}_{it-k} + \delta_3 i\text{ECT}_{it-1} + \varepsilon_3 it \tag{3}$$

The testable hypotheses are:

$$H_0 : \lambda_{3ik\,=\,0};\ \text{and}\ \delta_{3i} = 0 \quad \text{for}\ k = 1, 2, \ldots, q$$
$$H_A : \lambda_{3ik\,\#\,0};\ \text{and}\ \delta_{3i} \# 0 \quad \text{for}\ k = 1, 2, \ldots, q$$

$$\Delta\text{INN}_{it} = \alpha_{4j} + \sum_{k=1}^{p}\beta_{4ik}\,\Delta\text{GDP}_{it-k} + \sum_{k=1}^{q}\lambda_{4ik}\,\Delta\text{INN}_{it-k} + \delta_4 i\text{ECT}_{it-1} + \varepsilon_4 it \tag{4}$$

The testable hypotheses are:

$$H_0 : \lambda_{4ik\,=\,0};\ \text{and}\ \delta_{4i} = 0 \quad \text{for}\ k = 1, 2, \ldots, q$$
$$H_A : \lambda_{4ik\,\#\,0};\ \text{and}\ \delta_{4i} \# 0 \quad \text{for}\ k = 1, 2, \ldots, q,$$

where $i = 1, 2, \ldots., N$ represents a country in the panel, $t = 1, 2, \ldots.,$ and T represents the year in the panel.

This study uses HQIC[13] statistics to select the optimum lag length.

Moreover, the choice of a particular model (with/without ECT) depends upon the order of integration and the cointegrating relationship between innovation and per capita economic growth. Therefore, we first deploy unit root test and cointegration test, both at individual country and the panel setting, for knowing the order of integration and the presence of cointegrating relationship between innovation and per capita economic growth.

The Augmented Dickey Fuller (ADF) unit root test (Dickey and Fuller 1981) is used for individual country analysis, while the ADF—Fisher Chi-square panel unit root test (Maddala and Wu 1999) is used for the panel setting. On the other hand, Johansen cointegration test (Johansen 1988) is deployed for individual country analysis, while

Fisher/Maddala cointegration test (Maddala and Wu 1999; Fisher 1932) is deployed at the panel setting. The details of these two unit root tests (unit root and cointegration) are not available here and can be incorporated, if required.

Results and discussion

The discussion begins with order of integration and cointegration between innovation[14] and per capita economic growth. Using unit root (simple ADF test at each of the individual country and panel ADF[15] at the panel setting), we reject the null hypothesis of unit root at the first difference but not at the level data. Table 5 presents these unit root test results, both for individual country and for the European panel. The results indicate that innovation (INN: PAR, PAN, RDE, RRD, HTE, and STJ) and per capita economic growth (GDP) are non-stationary at the level data but are stationary at the first difference. This is true for all the 19 European countries, both at the individual country and at the group level (panel setting). The findings suggest that both innovation and per capita economic growth are integrated of order one [i.e. I (1)], which unbolts the possibility of cointegration between the two (innovation and per capita economic growth).

In the succeeding step, we deploy the Johansen Maximum Likelihood cointegration test (by λ_{Tra} and λ_{Max} test) at the individual country and Fisher cointegration test at the panel setting for checking the cointegration between innovation and per capita economic growth. The results of both the test statistics are reported in Tables 6, 7, and 8. Tables 6 and 7 report λ_{Tra} and λ_{Max} test statistics, respectively, while Table 8 reports the summary of cointegration test. These results indicate that innovation and per capita economic growth are cointegrated in some European countries,[16] while it is not cointegrated in rest of the countries.[17] The cointegration between innovation and per capita economic growth varies from case to case (for PAR, PAN, RDE, RRD, HTE, and STJ) and country to country (see Table 8).

The incidence of cointegration suggests that there is a long-run equilibrium relationship between innovation and per capita economic growth (Engle and Granger 1987). On the contrary, the absence of cointegration indicates that there is no long-run relationship between these two variables. The summary of these cointegration test results are reported in Table 8.

In the next section, we detect the Granger causality by deploying vector error correction model (VECM) for the presence of cointegration between innovation and per capita economic growth, and simple vector autoregressive (VAR) model for the absence of cointegration between the two. Having known the cointegration between the two, the next step is to determine the direction of causality between innovation and per capita economic growth. Using Granger causality test, the estimated results are reported in Tables 9, 10, 11, 12, and 13. Tables 9 and 10 report the presence of both short-run and long-run equilibrium relationship between innovation and per capita economic growth, while Tables 11, 12, and 13 report the summary of short-run Granger causal nexus between these two sets of variables (GDP vs. PAR; GDP vs. PAN; GDP vs. RDE; GDP vs. RRD; GDP vs. THE; and GDP vs. STJ). The analysis is based on the individual indicators of innovation and per capita economic growth. Coming to long-run equilibrium relationship,[18] we find the presence in a few cases,[19] while absence in remaining cases.[20] On the contrary, we have diverging experience in

Table 5 Results of unit root test

Countries	Variables						
	PAR	PAN	RDE	RRD	HTE	STJ	GDP
	LD/FD	LD/FD	LD/FD	LD/FD	LD/FD	LD/FD	LD/FD
Austria	0.14/−5.40*	1.82/−7.46*	3.81/−2.39**	−0.67/−3.22*	1.57/−5.10*	−1.30/−2.64**	−0.74/−5.64*
Belgium	0.05/−4.65*	1.06/−5.89*	1.81/−2.56**	−0.62/−2.46**	2.28/−2.96*	−1.32/−10.0*	−0.54/−5.84*
Czech Republic	−0.23/−2.33**	0.52/−2.36**	2.85/−1.89***	−1.31/−2.73**	−0.43/−2.06***	−0.69/−4.03*	−0.82/−6.61*
Denmark	−0.40/−5.90*	0.62/−6.66*	1.87/−1.98***	−0.99/−5.07*	−1.64/−6.91*	−0.34/−4.42*	−0.68/−7.68*
Finland	1.02/−4.07*	0.92/−3.91*	−0.22/−1.65***	0.43/−3.33*	−0.49/−3.32*	−1.25/−12.5*	−0.55/−3.49*
France	−0.31/−5.96*	0.63/−2.90*	−0.09/−3.52*	1.02/−5.83*	1.75/−5.14*	−0.76/−3.74*	−0.74/−5.73*
Germany	−1.11/−2.44**	−1.21/−3.09*	3.12/−2.44**	−1.63/−2.28**	1.99/−3.55*	−0.38/−3.81*	−1.16/−4.60*
Greece	−1.06/−5.36*	1.23/−5.27*	−/−	−/−	−1.56/−6.67*	−0.88/−2.39***	0.80/−3.63*
Hungary	1.63/−2.96*	0.73/−3.54*	−1.12/−2.84**	−1.79/−5.70*	1.41/−4.81*	−1.16/−4.44*	−1.40/−4.71*
Ireland	1.90/−2.83*	0.69/−3.75*	1.43/−1.88***	−3.93/−1.88***	−0.62/−2.96*	−0.77/−2.42**	−0.80/−3.12*
Italy	0.15/−3.03*	−0.94/−4.40*	1.46/−2.65**	−1.13/−3.88*	0.90/−7.60*	−0.29/−2.32**	−0.92/−6.04*
Netherlands	0.04/−4.52*	0.89/−3.21*	0.43/−2.47**	−1.54/−4.54*	1.08/−3.96*	−1.91/−2.23**	−0.65/−5.87*
Norway	0.17/−6.18*	−0.70/−2.83**	0.04/−2.47**	0.10/−2.72**	−0.24/−5.46*	−0.43/−3.54*	−0.23/−5.89*
Poland	0.22/−3.34*	0.47/−3.75*	−0.90/−2.02**	−2.49/−4.00*	−0.95/−2.37**	−0.46/−1.87***	−0.33/−5.20*
Portugal	−1.81/−4.83*	0.71/−3.88*	−1.59/−1.59***	−3.54/−1.84***	−2.10/−4.74*	−0.90/−2.88*	−1.10/−5.81*
Romania	0.80/−4.88*	0.47/−4.10*	0.23/−2.70**	0.82/−4.02*	−4.62/−2.51**	−1.92/−5.11*	1.58/−4.88*
Spain	−0.78/−5.21*	2.30/−4.59*	−1.67/−2.14**	−2.66/−2.66**	−0.93/−3.69*	−0.54/−2.53**	−0.67/−6.30*
Sweden	1.08/−3.28*	1.53/−5.36*	−1.27/−4.47*	0.14/−3.80*	−0.74/−4.93*	−1.46/−1.94***	−2.32/−7.96*
United Kingdom	0.90/−2.25**	−0.08/−2.32**	−0.54/−4.16*	−1.11/−2.50**	−0.97/−2.18***	−1.08/−4.06*	−0.69/−6.84*
European panel[#]	50.5/136.7*	14.8/129.1*	23.4/122.7*	18.0/95.4*	50.7/144.1*	113.3/104.1*	34.2/197.5*

PAR is number of patents by residents, PAN is number of patents by non-residents, RDE is research and development expenditure, RRD is researchers in research and development activities, HTE is high-technology exports, STJ is scientific and technical journal articles, and GDP is per capita economic growth. The investigation is done at three levels—no trend and intercept, with intercept, and with both intercept and trend. The results are more or less uniform; however, the reported statistics in the table present the ADF statistics at no trend and no intercept

*Statistical significance at 1% level; **statistical significance at 5% level; ***statistical significance at 10% level

[#]The reported statistics are calculated at the panel level

Table 6 Results of Johansen-Juselius Cointegration Test (Max Test)

Countries	Cointegration with GDP					
	PAR	PAN	RDE	RRD	HTE	STJ
Austria	14.5*/4.55*	15.9/* 7.73*	24.1*/10.2*	13.7/3.35	14.8/0.85	18.3*/5.67*
Belgium	28.8*/1.95	8.97/2.87	9.75/0.81	13.8/1.26	10.2/0.16	14.7*/5.74*
Czech Republic	9.93/0.07	12.3/0.48	14.1/2.52	13.3/0.57	13.9/4.34	10.4/0.67
Denmark	9.43/1.55	36.6*/7.46*	23.9*/3.18	1.9/1.61	20.7*/3.51	16.1*/0.83
Finland	13.5/0.11	17.1*/5.76*	18.4*/4.52*	7.43/0.15	17.*/0.15	38.2*/14.6*
France	18.8*/3.53	22.0*/0.97	12.3/2.74	15.5*/0.20	13.9/1.51	22.2*/7.72*
Germany	16.4*/7.96*	15.4*/0.81	12.2/0.48	11.4/0.78	17.4*/0.37	20.2*/5.09*
Greece	9.43/0.01	10.9/1.17	–/–	–/–	3.99/0.01	9.63/2.46
Hungary	11.4/3.60	18.96*/2.89	9.52/0.01	15.0*/0.43	13.7/5.46*	13.7/2.29
Ireland	5.78/0.14	10.2/0.18	12.0/0.31	12.5/0.11	10.2/0.78	7.45/2.56
Italy	–/–	–/–	13.1/0.19	12.3/0.01	16.2*/0.74	30.9*/8.71*
Netherlands	8.80/3.55	20.5*/5.00*	20.3*/2.88	11.3/0.01	18.4*/5.07*	15.0*/1.07
Norway	14.7*/3.25	13.4/0.04	18.3*/3.96*	20.2*/5.26*	18.5*/3.40	11.7/0.41
Poland	12.2/0.04	8.28/0.58	12.8/0.01	14.2*/0.18	10.2/0.30	13.9/2.54
Portugal	14.8*/0.46	8.83/3.38	13.4/1.78	10.3/0.03	11.5/2.66	17.4*/4.45*
Romania	10.10/4.31	8.50/0.45	24.4*/0.01	39.9*/9.95*	17.2*/4.97*	8.05/0.06
Spain	13.3/1.53	10.05/1.61	17.0*/3.79	20.2*/6.72*	15.0*/4.55*	20.3*/4.82*
Sweden	15.7*/0.44	12.3/0.03	8.61/2.36	10.9/1.19	16.6*/4.56*	21.8*/5.57*
United Kingdom	11.57/0.26	17.6*/3.83	20.5*/4.77*	19.9*/7.82*	14.2*/0.01	20.2*/4.87*
European panel	107.9*/77.8*	104.5*/58.6*	99.56*/79.17*	108.9*/76.37*	128.5*/68.73*	96.1*/64.6*

PAR is number of patents by residents, PAN is number of patents by non-residents, RDE is research and development expenditure, RRD is researchers in research and development activities, HTE is high-technology exports, STJ is scientific and technical journal articles, and GDP is per capita economic growth. We observe statistical significance at 5% level
*Indicates the statistical significance of the cointegrating vector and confines the presence of cointegration between innovation and per capita economic growth

the context of short-run Granger causality between innovation and per capita economic growth. These results are presented below.

Case 1: between patents-residents (PAR) and per capita economic growth (GDP)

For countries like Belgium, Finland, France, Germany, Greece, Italy, the Netherlands, Portugal, Romania, and the UK, we find the unidirectional causality from innovation to per capita economic growth (PAR => GDP), whereas for countries like Czech Republic, Denmark, Hungary, Ireland, and Norway, we find unidirectional causality from per capita economic growth to innovation (PAR <= GDP). Additionally, for countries like Austria, Poland, Spain, and Sweden, and the European panel, we find the bidirectional causality between innovation and per capita economic growth (PAR <=> GDP).

Case 2: between patents-non-residents (PAN) and per capita economic growth

For countries like Austria, Belgium, Czech Republic, France, the Netherlands, Romania, Spain, and Sweden, there is a unidirectional causality from innovation to per capita economic growth (PAN => GDP), whereas for Finland, Germany, Greece, and Norway, we find unidirectional causality from per capita economic growth to innovation (GDP => PAN). Additionally, for countries like Denmark, Hungary, Ireland, Portugal, and the

Table 7 Results of Johansen-Juselius Cointegration Test (Trace Test)

Countries	Cointegration with GDP					
	PAR	PAN	RDE	RRD	HTE	STJ
Austria	19.6*/4.55*	21.2*/7.30*	13.9*/10.2*	10.3/3.35	13.9/0.90	16.6*/5.66*
Belgium	30.7/1.95	11.8/2.87	8.93/0.82	12.5/1.26	10.0/0.16	8.91/5.74
Czech Republic	9.99/0.07	12.8/0.48	11.6/2.52	12.7/0.57	9.61/4.34	9.75/0.67
Denmark	10.9/1.55	44.1*/7.46*	20.7*/3.18	10.3/1.61	17.1*/3.50	18.2*/0.83
Finland	13.6/0.11	22.9*/5.76*	18.8*/4.52*	7.29/0.15	17.1*/0.15	23.5*/14.6*
France	18.3*/3.43	23.1*/0.97	9.55/2.74	15.3*/0.20	12.4/1.51	13.5*/7.72*
Germany	24.3*/7.96*	16.2*/0.81	11.7/0.48	10.6/0.78	17.0*/0.37	15.1*/5.09*
Greece	9.43/0.01	12.0/1.17	–/–	–/–	3.99/0.01	7.17/2.46
Hungary	14.9*/3.60	21.9*/2.89	9.56/0.01	15.0*/0.43	8.24/5.46*	11.4/2.29
Ireland	5.92/0.14	10.4/0.18	11.7/0.31	12.4/0.11	9.39/0.78	4.89/2.56
Italy	–/–	–/–	12.97/0.16	12.3/0.01	15.5*/0.75	22.2*/8.71*
Netherlands	14.4*/3.55	20.5*/5.00*	17.4*/2.88	11.3/0.01	18.3*/5.07*	14.8*/1.07
Norway	17.9*/3.26	13.45/0.04	14.5*/3.96*	17.9*/5.26*	15.1*/3.40	11.7/0.41
Poland	12.2/0.04	8.28/0.58	12.8/0.01	14.0*/0.18	9.85/0.30	11.3/2.54
Portugal	15.3*/0.46	14.2/3.38	11.6/1.78	10.3/0.03	8.79/2.66	12.97*/4.45*
Romania	14.4/3.31	8.95/0.45	24.4*/0.01	29.9*/9.95*	12.2*/4.97*	4.99/0.06
Spain	14.9*/1.53	11.6/1.61	17.3*/3.79	13.5*/6.72*	20.5*/4.55*	15.2*/4.82*
Sweden	16.2*/0.44	12.4/0.03	6.25/2.37	9.67/1.19	12.0*/4.56*	16.3*/5.57*
United Kingdom	11.8/0.26	21.4*/3.83	15.76/4.77*	22.0*/7.82*	14.6/0.01	15.3*/4.87*
European panel	128.3*/77.83*	112.2*/58.63*	80.21*/79.17*	88.87*/76.37*	112.5*/68.73*	96.1*/64.6*

PAR is number of patents by residents; PAN is number of patents by non-residents; RDE is research and development expenditure; RRD is researchers in research and development activities; HTE is high-technology exports; STJ is scientific and technical journal articles; and GDP is per capita economic growth. We observe statistical significance at 5% level
*Indicates the statistical significance of the cointegrating vector and confines the presence of cointegration between innovation and per capita economic growth

UK, and the European panel, we find bidirectional causality between innovation and per capita economic growth (PAN <=> GDP), while in the context of Italy, and Poland, we find per capita economic growth does not Granger-cause innovation (GDP <#> PAN).

Case 3: between R&D expenditure (RDE) and per capita economic growth

For countries like Belgium, Denmark, Finland, France, Germany, Italy, Norway, Poland, Portugal, Sweden, and the UK, we detect the unidirectional causality from innovation to per capita economic growth (RDE => GDP), whereas for countries like Austria, Czech Republic, Ireland, the Netherlands, Romania, and Spain, we find the unidirectional causality from per capita economic growth to innovation (GDP => RDE). Additionally, for European panel, we find the existence of bidirectional causality between innovation and per capita economic growth (RDE <=> GDP), while in the context of Greece, per capita economic growth does not Granger-cause innovation (RDE <#> GDP).

Case 4: between researchers in R&D activities (RRD) and per capita economic growth (GDP)

For Austria, Belgium, Czech Republic, France, Germany, Hungry, Italy, Portugal, and the UK, there is a unidirectional causality from innovation to per capita economic growth (RRD => GDP), whereas for Denmark, Finland, Ireland, the Netherlands,

Table 8 Summary of cointegration test results

Cointegrated status					
Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Austria (2)	Austria (2)	Austria (2)	Austria (0)	Austria (0)	Austria (2)
Belgium (1)	Belgium (0)	Belgium (0)	Belgium (0)	Belgium (0)	Belgium (2)
CR (0)	CR (0)	CR (0)	CR (0)	CR (0)	CR (0)
Denmark (0)	Denmark (2)	Denmark (1)	Denmark (0)	Denmark (1)	Denmark (0)
Finland (0)	Finland (2)	Finland (2)	Finland (0)	Finland (1)	Finland (2)
France (1)	France (1)	France (0)	France (1)	France (0)	France (2)
Germany (2)	Germany (1)	Germany (0)	Germany (0)	Germany (1)	Germany (2)
Greece (0)	Greece (0)	Greece (0)	Greece (0)	Greece (0)	Greece (0)
Hungary (0)	Hungary (1)	Hungary (0)	Hungary (1)	Hungary (1)	Hungary (0)
Ireland (0)	Ireland (0)	Ireland (0)	Ireland (0)	Ireland (0)	Ireland (0)
Italy (0)	Italy (0)	Italy (0)	Italy (0)	Italy (1)	Italy (2)
Netherlands (0)	Netherlands (2)	Netherlands (1)	Netherlands (0)	Netherlands (2)	Netherlands (1)
Norway (1)	Norway (0)	Norway (2)	Norway (2)	Norway (1)	Norway (0)
Poland (0)	Poland (0)	Poland (0)	Poland (1)	Poland (0)	Poland (0)
Portugal (1)	Portugal (0)	Portugal (0)	Portugal (0)	Portugal (0)	Portugal (2)
Romania (0)	Romania (0)	Romania (1)	Romania (2)	Romania (2)	Romania (0)
Spain (0)	Spain (0)	Spain (2)	Spain (2)	Spain (2)	Spain (2)
Sweden (1)	Sweden (0)	Sweden (0)	Sweden (0)	Sweden (2)	Sweden (2)
UK (0)	UK (2)	UK (2)	UK (2)	UK (1)	UK (2)
EP (2)	EP (2)	EP (2)	EP (2)	EP (2)	EP (2)

Case 1: cointegration between *PAR* and GDP; case 2: cointegration between *PAN* and GDP; case 3: cointegration between *RDE* and GDP; case 4: cointegration between *RRD* and GDP; case 5: cointegration between *HTE* and GDP; case 6: cointegration between *STJ* and GDP. PAR is number of patents by residents, PAN is number of patents by non-residents, RDE is research and development expenditure, RRD is researchers in research and development activities, HTE is high-technology exports, STJ is scientific and technical journal articles, and GDP is per capita economic growth. 0 stands for absence of cointegration between innovation (PAR/PAN/RDE/RRD/HTE/STJ) and per capita economic growth, 1 stands for presence of one cointegrating vector between innovation (PAR/PAN/RDE/RRD/HTE/STJ) and per capita economic growth, and 2 stands for presence of two cointegrating vectors between innovation (PAR/PAN/RDE/RRD/HTE/STJ) and per capita economic growth. Parentheses indicate number of cointegrating vector (s). Results are derived on the basis of Tables 6 and 7 results
CR Czech Republic, *UK* United Kingdom, *EP* European panel

Norway, Poland, and Spain, we find per capita economic growth Granger-causes innovation (RRD <= GDP). Additionally, for Romania, and the European panel, there is bidirectional causality between innovation and per capita economic growth (RRD <=> GDP), while in the context of Greece and Sweden, per capita economic growth does not Granger-cause innovation (RRD <#> GDP).

Case 5: between high-technology exports (HTE) and per capita economic growth

For countries like Belgium, France, Ireland, the Netherlands, and Sweden, we find the presence of unidirectional causality from innovation to per capita economic growth (HTE = > GDP), whereas for countries like Hungary, Italy, Norway, Poland, Portugal, Romania, and Spain, we find the presence of unidirectional causality from per capita economic growth to innovation (GDP => HTE). Moreover, for countries like Finland, Germany, and the UK, and the European panel, there is bidirectional causality between innovation and per capita economic growth (HTE <=> GDP), while in the context of

Table 9 Results of test from error correction model

Countries	Granger causality test between					
	PAR and GDP		PAN and GDP		RDE and GDP	
	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Austria	4.90*/4.16*	−3.39*/−1.33	8.97*/−1.90	−1.79/−1.03	0.634/6.37*	−0.25/−4.17*
Belgium	18.9*/1.21	−2.46/−0.53	3.62**/1.48	−2.12/1.13	3.55*/0.28	NA/NA
Czech Republic	1.62/4.35*	NA/NA	3.27**/0.74	NA/NA	1.17/4.91*	NA/NA
Denmark	0.42/4.32**	NA/NA	3.16**/9.69*	−1.83/−3.21**	20.6*/0.11	−6.03*/−2.67
Finland	4.32*/0.31	NA/NA	0.57/5.29*	−1.20/2.03	4.39*/1.08	−1.56/1.75
France	3.19**/0.60	−2.83/−1.12	13.8*/2.57	2.91/−1.41	3.93*/2.00	NA/NA
Germany	3.34**/1.01	−3.27*/−0.82	0.72/12.2*	−4.03*/−2.92**	9.32*/1.24	NA/NA
Greece	6.73*/0.12	NA/NA	1.09/8.64*	NA/NA	−/−	−/−
Hungary	1.51/5.58*	NA/NA	4.50*/5.28*	−2.03/−1.57	4.77*/1.94	NA/NA
Ireland	0.63/3.95*	NA/NA	3.25**/5.63*	NA/NA	0.33/4.33	NA/NA
Italy	6.74*/0.71	NA/NA	0.49/1.87	NA/NA	5.09*/1.50	NA/NA
Netherlands	3.26**/0.90	NA/NA	3.64**/2.23	−2.38/−1.57	0.34/4.44*	−2.52/−0.33
Norway	2.83/14.5*	−0.85/−5.06*	1.62/23.8*	NA/NA	4.72*/0.79	0.30/−1.60
Poland	14.3*/5.46*	NA/NA	0.67/1.42	NA/NA	3.97*/1.78	NA/NA
Portugal	5.19*/1.20	−3.69***/1.28	4.09**/16.8*	NA/NA	10.3*/0.21	NA/NA
Romania	5.10*/0.86	NA/NA	3.69*/2.07	NA/NA	0.80/5.37*	−4.41/−3.07**
Spain	4.21*/4.56*	NA/NA	5.42*/0.96	NA/NA	0.23/7.71*	−1.73/−3.03**
Sweden	8.93*/13.5*	−4.10*/−2.33	7.15*/0.13	NA/NA	3.36*/2.28	NA/NA
United Kingdom	2.99**/0.33	NA/NA	10.1*/3.81**	−4.69*/−2.97**	3.69*/1.94	−1.16/−2.19
European panel	5.91*/10.1*	−6.09*/−2.60	0.45/6.61*	−6.23*/−2.38	2.84*/6.08*	−5.34*/−1.14

GDP is per capita economic growth; PAR is the number of patents by residents; PAN is the number of patents by non-residents; and RDE is research and development expenditure. The short-run causality is detected through the Wald statistics, while long-run causality is detected through the statistical significance of error correction term. For both short-run and long-run, the first value represents GDP as the dependent variable and the second value represents innovation (PAR/PAN/RDE) as the dependent variable
*Indicates the statistical significance at 5% level; **indicates the statistical significance at 10% level

Austria, Czech Republic, Denmark, Greece, and Poland, per capita economic growth does not Granger-cause innovation (HTE <#> GDP).

Case 6: between scientific and technical journal articles (STJ) and per capita economic growth

For countries like Finland, France, Hungary, Romania, and Spain, we detect the presence of unidirectional causality from innovation to per capita economic growth (STJ => GDP), whereas for countries like Austria, Belgium, Denmark, Germany, Ireland, Italy, and the UK, and the European panel, we find the presence of unidirectional causality from per capita economic growth to innovation (GDP => STJ). Additionally, for countries like Greece, the Netherlands, Norway, Poland, Portugal, and Sweden, we observe bidirectional causality between innovation and per capita economic growth (STJ <=> GDP), while in the context of Czech Republic, we find that per capita economic growth does not Granger cause innovation (STJ <#> GDP).

As is evident by these individual country results,[21] the nature of causal relationship between innovation and per capita economic growth is more or less country specific and innovation indicator specific.[22]

Table 10 Results of test from error correction model

Countries	Granger causality test between					
	RRD and GDP		HTE and GDP		STJ and GDP	
	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Austria	3.20**/0.40	NA/NA	0.89/0.63	−3.18**/−0.99	1.64/6.54*	−1.53/−2.13
Belgium	13.6*/1.19	NA/NA	3.40*/0.48	NA/NA	0.32/5.03*	−1.29/−2.85
Czech Republic	5.14*/0.41	NA/NA	1.76/0.01	NA/NA	1.27/0.43	NA/NA
Denmark	0.46/5.28*	NA/NA	0.51/0.19	−1.92/−2.26	0.06/21.1*	−1.96/−4.13*
Finland	0.07/25.3*	NA/NA	18.3*/3.73**	−3.46**/−0.32	36.8*/0.92	−6.10/−2.12
France	3.12**/2.12	−2.35/−1.13	3.41*/0.09	NA/NA	8.21*/0.44	−0.66/−5.31*
Germany	5.31*/0.18	NA/NA	12.2*/3.07**	−5.94*/−1.82	0.40/4.06*	−2.65/−1.93
Greece	–/–	–/–	1.33/1.85	–/–	8.49*/5.33*	–/–
Hungary	7.12*/0.46	−4.14*/−1.26	1.20/19.6*	−2.25/−4.37*	5.29*/0.97	NA/NA
Ireland	0.99/3.62**	NA/NA	18.1*/0.26	NA/NA	2.02/4.19*	NA/NA
Italy	4.43*/0.47	NA/NA	2.10/9.59*	−3.64*/−2.07	0.02/11.4	−0.65/−4.68*
Netherlands	1.34/6.33*	NA/NA	7.60*/1.18	0.22/−2.65	3.51*/5.59*	NA/NA
Norway	0.01/5.86*	NA/NA	0.90/4.97*	−0.16/−3.90*	2.89**/6.04*	NA/NA
Poland	0.75/5.68*	−0.86/−1.90	0.67/3.03**	NA/NA	3.48**/3.05**	NA/NA
Portugal	9.83*/1.46	NA/NA	1.33/3.53*	NA/NA	17.9*/3.57**	−4.52*/−1.35
Romania	3.84*/3.74*	−7.97*/1.96	0.50/3.66*	−1.26/−3.61**	3.87*/1.85	NA/NA
Spain	0.15/6.46*	−0.62/−3.14	1.04/11.3*	NA/NA	5.58*/2.05	−1.15/−4.73*
Sweden	1.45/0.15	NA/NA	3.26*/0.87	−3.52**/−0.66	8.15*/4.55*	NA/NA
United Kingdom	9.47*/2.25	NA/NA	25.9*/0.82	NA/NA	1.14/9.10*	NA/NA
European panel	3.03*/2.95*	−6.15*/−1.23	7.95*/4.41*	−6.31*/−1.69	2.13/6.88*	−7.09*/−2.56

RRD is the researchers in research and development activities; HTE is the high-technology exports; STJ is the scientific and technical journal articles; and GDP is per capita economic growth. The short-run causality is detected through the Wald statistics, while long-run causality is detected through the statistical significance of error correction term. For both short-run and long-run, the first value represents GDP as the dependent variable and the second value represents innovation (RRD/HTE/STJ) as the dependent variable
*Indicates the statistical significance at 5% level; **indicates the statistical significance at 10% level

Conclusion

The level and structure of innovation should not be ignored because it plays an imperative role in stimulating economic growth (Pradhan et al. 2016; Hassan and Tucci 2010). This study explored the Granger causal nexus between innovation and per capita economic growth for the 19 European countries using time series data from 1989 to 2014. The pivotal message from our study for the policymakers and academicians alike is that implications drawn from research on per capita economic growth that disregard the dynamic interrelation of the two variables will be imperfect. It is the conjoined back-and-forth relationship between innovation and per capita economic growth that builds our study and guides the future research on this topic.

Our study acknowledges mixed evidence on the relationship between the innovation and per capita economic growth in the 19 European countries, both at the individual country and at the panel setting. In some instances, per capita economic growth leads to innovation, lending support to demand-following hypothesis of innovation-growth nexus. In some other instances, it is innovation that regulates the level of per capita economic growth, lending support to supply-leading hypothesis of innovation-growth nexus. There are also circumstances, where innovation and per capita economic growth

Table 11 Summary of Granger causality test

Countries	Nature of Granger causality between					
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
	PAR and GDP	PAN and GDP	RDE and GDP	RRD and GDP	HTE and GDP	STJ and GDP
Austria	FBH	SLH	DFH	SLH	NEH	DFH
Belgium	SLH	SLH	SLH	SLH	SLH	DFH
Czech Republic	DFH	SLH	DFH	SLH	NEH	NEH
Denmark	DFH	FBH	SLH	DFH	NEH	DFH
Finland	SLH	DFH	SLH	DFH	FBH	SLH
France	SLH	SLH	SLH	SLH	SLH	SLH
Germany	SLH	DFH	SLH	SLH	FBH	DFH
Greece	SLH	DFH	–	–	NEH	FBH
Hungary	DFH	FBH	SLH	SLH	DFH	SLH
Ireland	DFH	FBH	DFH	DFH	SLH	DFH
Italy	SLH	NEH	SLH	SLH	DFH	DFH
Netherlands	SLH	SLH	DFH	DFH	SLH	FBH
Norway	DFH	DFH	SLH	DFH	DFH	FBH
Poland	FBH	NEH	SLH	DFH	DFH	FBH
Portugal	SLH	FBH	SLH	SLH	DFH	FBH
Romania	SLH	SLH	DFH	FBH	DFH	SLH
Spain	FBH	SLH	DFH	DFH	DFH	SLH
Sweden	FBH	SLH	SLH	NEH	SLH	FBH
United Kingdom	SLH	FBH	SLH	SLH	SLH	DFH
European panel	FBH	DFH	FBH	FBH	FBH	DFH

Case 1: cointegration between *PAR* and GDP; case 2: cointegration between *PAN* and GDP; case 3: cointegration between *RDE* and GDP; case 4: cointegration between *RRD* and GDP; case 5: cointegration between *HTE* and GDP; case 6: cointegration between *STJ* and GDP. PAR is number of patents by residents, PAN is number of patents by non-residents, RDE is research and development expenditure, RRD is researchers in research and development activities, HTE is high-technology exports, STJ is scientific and technical journal articles, and GDP is per capita economic growth. SLH indicates the unidirectional causality from innovation to economic growth, DFH indicates the unidirectional causality from economic growth to innovation, FBH indicates the bidirectional causality between innovation and economic growth, and NEH indicates no causal flow between innovation and economic growth. Results are derived on the basis of Tables 9 and 10 results

are mutually interdependent. That is the situation where both are self-reinforcing and offer support to feedback hypothesis of innovation-growth nexus. Additionally, there are also cases where innovation and per capita economic growth are independent of each other. That is the situation where both are neutral and offer support to neutrality hypothesis of innovation-growth nexus.

The study accordingly suggests that in order to promote per capita economic growth, attention must be paid to policy strategies that promote innovation. Given the possibility of reverse causality or bidirectional causality for some cases, policies that increase per capita economic growth (such as actions to increase investment) would be desirable to bring more innovation in the economy. Consequently, it is suggested that government should play a more positive role in order to foster innovation and then integrate it with per capita economic growth. No doubt, in recent times, many countries including European countries have recognized the importance of innovation for high economic growth and consequently, they have increased their effort to have more innovation in their countries. Nonetheless, what is needed is that government of the respective countries should pay higher attention to bring the steady environment in order to

Table 12 Summary of Granger causality test results

Supply-leading hypothesis of innovation-growth nexus			Demand-following hypothesis of innovation-growth nexus		
Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
	Austria				Austria
Belgium	Belgium	Belgium			Czech Republic
	Czech Republic		Czech Republic		Ireland
		Denmark			
Finland		Finland	Denmark		Netherlands
France	France	France		Finland	Romania
Germany		Germany		Germany	Spain
Greece		Hungary		Greece	
Italy	Italy	Italy	Hungary		
Netherlands	Netherlands	Norway	Ireland		
		Poland	Norway	Norway	
		Portugal		European panel	
Portugal		Sweden			
Romania	Romania	United Kingdom			
	Spain				
	Sweden				
United Kingdom					
Feedback hypothesis of innovation-growth nexus			Neutrality hypothesis of innovation-growth nexus		
Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Austria					
	Denmark	Finland			
		Greece			
	Hungary			Italy	
	Ireland	Ireland			
		Netherlands			
Poland					
	Portugal			Poland	
Spain					
Sweden					
	United Kingdom				
European panel		European panel			

Case 1: cointegration between *PAR* and GDP; case 2: cointegration between *PAN* and GDP; case 3: cointegration between *RDE* and GDP. PAR is the number of patents by residents, PAN is the number of patents by non-residents, RDE is research and development expenditure, and GDP is per capita economic growth. Results are derived on the basis of Table 11 results

promote the link between innovation and per capita economic growth. This requires the followings. First, government everywhere can acknowledge the importance of innovation for long-term growth. This is most evident in those countries where the easy options have been exhausted and future growth depends on more efficient ways of combining inputs or producing new or improved outputs. Second, government can nurture innovation indirectly by providing an appropriate environment for firms that are willing to invest more and innovate. They can also support innovation directly, by either funding public research or encouraging private investment in research and innovation. The cited examples are through innovation-related tax incentives and

Table 13 Summary of Granger causality test results

Supply-leading hypothesis of innovation-growth nexus			Demand-following hypothesis of innovation-growth nexus		
Case 4	Case 5	Case 6	Case 4	Case 5	Case 6
Austria					Austria
Belgium	Belgium				Belgium
Czech Republic		Finland	Czech Republic		
France	France	France	Denmark		Denmark
Germany		Hungary	Finland		
Greece				Finland	
Hungary					Germany
Italy	Italy			Hungary	Ireland
Portugal	Netherlands		Hungary	Norway	Italy
United Kingdom			Ireland	Poland	
			Netherlands	Portugal	
	Romania	Romania	Norway	Romania	
	Spain	Spain	Poland	Spain	United Kingdom
	Sweden		Portugal		European panel
Feedback hypothesis of innovation-growth nexus			Neutrality hypothesis of innovation-growth nexus		
Case 4	Case 5	Case 6	Case 4	Case 5	Case 6
Austria			United Kingdom	Austria	
	Finland	Netherlands		Czech Republic	Czech Republic
	Germany	Norway		Denmark	
		Poland		Greece	
	Ireland	Portugal			
		Sweden			
Poland					
	Portugal				
Spain					
Sweden					
	United Kingdom				
European panel	European panel				

Case 4: cointegration between *RRD* and GDP; Case 5: cointegration between *HTE* and GDP; Case 6: cointegration between *STJ* and GDP. RRD is researchers in research and development activities, HTE is high-technology exports, STJ is scientific and technical journal articles, and GDP is per capita economic growth. Results are derived on the basis of Table 11 results

grants. Third, there is requirement of policy options for sector-wise level importance, depending upon the particular requirement of country's development. This requires governments to make difficult choices, striking a balance between improvements in the general environment for innovation and direct support for innovation, targeted or not to specific (groups of) actors. The combination of policy objectives and instruments should be tailored to a country's level of development and the strengths and weaknesses of its innovation system, so it should vary both across countries and over time (see, for instance, Veugelers and Schweiger 2016).

Over and above, our study is strictly constrained to examine the causal nexus between innovation activities and economic growth. So, we have not included other relevant factors, such as capital, labour, infrastructure, entrepreneurship, and venture capital (see, for instance, Galindo and Mendez-Picazo (2014), Navas (2015), Samila and Sorenson (2011), Santacreu (2015)), in our empirical investigation process. The inclusion of these factors may affect our main findings and this could be a subject of future research. Additionally, the other limitations do exist in this study. First, no indirect or complementary effects on the nexus between innovation activities and economic growth; second, exclusion of sector-wise impact of innovation activities on economic growth; third, small time-dimension of data, i.e. from 1989 to 2014; and fourth, the findings are regulated to European countries only. Consequently, further study in these mutable areas can produce more inspiring and spontaneous findings to the nexus between innovation and economic growth.

Endnotes

[1]The specification is mostly due to the fact that innovation can be considered important for potential economic growth. So what evidence do we have that innovation is linked to economic growth, and at what levels of analysis? (Bottazzi and Peri 2003; Cameron 1998; Coad et al. 2016; Hassan and Tucci 2010; Hsu et al. 2014).

[2]Innovation is a notion that has been defined and generalized in many ways by both researchers and policymakers, both as a process and as an outcome (Garcia and Calantone 2002; Grossman and Helpman 1991, 1994; OECD 2005a; Raymond and St-Pierre 2010).

[3]When Schumpeter wrote about innovation, he clearly intended to emphasize not only the "destructive" aspect of creative destruction, but the "creative" part as well (Aghion and Howitt, 1992; Freeman and Soete 1997; Hassan and Tucci 2010).

[4]See Agenor and Neanidis (2015), Aghion and Howitt (2009), Corrado et al. (2012; 2013); Dachs and Peters (2014), de Serres et al. (2006), Dosi (1988), Fagerberg (1994), Fan (2011), Galindo and Mendez-Picazo (2013), Grossman (2009), Grossman and Helpman (1994), Hanley et al. (2011), Hsu et al. (2015), Hudson and Minea (2013), Huang (2011), Kirchhoff (1994), Laeven et al. (2015), Mandel (2009), Navas (2015), OECD (2005b, 2007), Petrakis et al. (2015), Rogers (1995), Roig-Tierno et al. (2015), Sohag et al. (2015), Tellis et al. (2008), and Wennekers (1999).

[5]It can be noted that most of the previous works on "innovation-growth nexus" are flooded with production function approach and lacks in Granger causality approach.

[6]The choice of these six innovation indicators are with respect to data availability in the European countries.

[7]The choice of these time periods is as per the data availability.

[8]The rejection of H^{0}_{1A} ensures the case of SLH; the rejection of H^{0}_{1B} ensures the case of DFH, the rejection of both ($H^{0}_{1A}$and H^{0}_{1B}) ensure the case of FBH, and the acceptance of both ($H^{0}_{1A}$and H^{0}_{1B}) ensures the case of NEH.

[9]GDP represents the level of economic growth.

[10]INN is used here as a proxy for six different innovation indicators, such as PAR, PAN, RDE, RRD, HTE, and STJ. Table 1 provides a detailed discussion of these variables.

[11]These include Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Norway, Poland, Portugal, Romania, Spain, Sweden, the Netherlands, and the UK.

[12]The involvement of ECT in the model depends upon the presence of cointegration between innovation (any of the indicators from PAR, PAN, RDE, RRD, HTE, and STJ) and per capita economic growth. The ECT will be removed in the estimation process, if innovation and per capita economic growth are not cointegrated.

[13]HQIC stands for Hannan-Quinn Information Criterion and it is the most appropriate for choosing optimum lag length (see, for instance, Brooks (2014)).

[14]It is with respect to PAR, PAN, RDE, RRD, HTE, and STJ.

[15]Panel ADF stands for ADF—Fisher Chi-square panel unit root test (Maddala and Wu 1999)

[16]These include Austria, Belgium, Germany, Finland, Italy, France, the Netherlands, and Sweden.

[17]These include Czech Republic, Denmark, Greece, Hungary, Ireland, Italy, Norway, Poland, Portugal, Spain, and the UK.

[18]Detected through the significance of error correction term (ECT) (see Eqs. 1–4).

[19]These include Austria, Belgium, Germany, Norway, Portugal, Sweden and the European panel in case 1; Austria, Denmark, Finland, France, Germany, the Netherlands, the UK and the European panel in case 2; Austria, Denmark, Finland, the Netherlands, Norway, Romania, Spain, the UK and the European panel in case 3; Hungary, Norway, Poland, Romania, Spain, the UK, and the European panel in case 4; Denmark, Germany, Italy, the Netherlands, Norway, Romania, Spain, Sweden, the UK, and the European panel in case 5; and Austria, Belgium, Finland, France, Germany, Italy, the Netherlands, Portugal, Spain, Sweden, the UK, and the European panel in case 6.

[20]These include Czech Republic, Greece, Ireland, Italy, Poland, Romania and Spain in all the three cases.

[21]The small sample size of this study may hinder the generalizability of our findings. However, the sample size is well representative of a few countries and at the panel level. Moreover, we have conducted some robustness checks for this analysis. These include (1) deployment of normalized data for both innovation indicators and per capita economic growth, (2) incorporation of additional unit root tests (KPSS (Kwiatkowski et al. 1992) unit root test at the individual country and LLC (Levine et al. 2002) unit root test at the panel level) to know the order of integration, (3) deployment of additional cointegration tests (Engle and Granger (1987) at individual country level and Pedroni (1999) test at the panel level), and (4) testing the VECM/VAR model by changing lag structure. Our results are more or less consistent with these robustness checks.

[22]It is mostly due to the involvement of different innovation indicators, namely PAR, PAN, RDE, RRD, HTE, and STJ.

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Authors' contributions
We declare that all authors have equal contribution in this paper. All authors read and approved the final manuscript.

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