IIMB Management Review (2019) 31, 268–282

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/iimb

Innovation and economic growth in European Economic Area countries: The Granger causality approach

Rana Pratap Maradana[a], Rudra P. Pradhan[b,*], Saurav Dash[c], Danish B. Zaki[d], Kunal Gaurav[b], Manju Jayakumar[b], Ajoy K. Sarangi[e,b]

[a] *Thiagarajar School of Management, Madurai, Tamil Nadu, India*
[b] *Vinod Gupta School of Management, Indian Institute of Technology, Kharagpur, West Bengal, India*
[c] *Vellore Institute of Technology, Vellore, Tamil Nadu, India*
[d] *The Shipping Corporation of India, Mumbai, Maharashtra, India*
[e] *National Informatics Centre, Baripada, Odisha, India*

Received 31 October 2016; Accepted 27 March 2019; Available online 3 April 2019

KEYWORDS
Innovation;
Per capita economic growth;
Granger causality;
EEA countries

Abstract The paper examines the long-run relationship between innovation and economic growth in the European Economic Area (EEA) countries for the period 1989–2014. Using vector auto-regressive model for testing the Granger causalities, the study finds the presence of both unidirectional and bidirectional causality between innovation and economic growth. These results vary from country to country, depending upon the types of innovation indicators that are used in the empirical investigation process. The policy implication of this study is that economic policies should recognise the differences in innovation and economic growth in order to maintain sustainable development in EEA countries.

Introduction

Innovation[1] has been considered key to economic growth, particularly since the seminal work of Schumpeter (1932),[2] and critically important in contemporary economies (Coad, Segarra & Teruel, 2016; Hausman & Johnston, 2014). It helps the economy on multiple fronts,[3] predominantly on economic growth[4] (Agenor & Neanidis, 2015; Fan, 2011;

* Corresponding author. Tel.: +91 3222 282316
E-mail address: rudrap@vgsom.iitkgp.ernet.in (R.P. Pradhan).

[1] Innovation is a concept that has been defined and characterised in many ways by researchers, both as a process and as an outcome (for instance, Maradana, Pradhan, Dash, Gaurav, Jayakumar & Chatterjee, 2017; Garcia & Calantone, 2002; Kim & Lee, 2015; OECD, 2005a; Raymond & St-Pierre, 2010).

[2] Schumpeter was an early thinker on the relationship between innovation and economic growth at a more macro level (Cameron, 1998; Freeman & Soete, 1997; Grossman & Helpman, 1991; Kirchhoff, 1994; Schumpeter, 1911, 1932).

[3] Innovation has its own externalities (Bae & Yoo, 2015). The accrual of technological innovation enlarges the knowledge base and makes successive innovations available over time (Stokey, 1995).

[4] The necessity of linking innovation and economic growth is also briefly explained in Appendix A.

https://doi.org/10.1016/j.iimb.2019.03.002
0970-3896

Grossman, 2009; Grossman & Helpman, 1994; Hudson & Minea, 2013; OECD, 2007; Rogers, 1995); global competitiveness (Galindo & Mendez, 2014; Huang, 2011; Petrakis, Kostis & Valsamis, 2015); financial systems (Aghion & Howitt, 2009; Corrado, Haskel, Jona-Lasinio & Iommi, 2013; de Serres, Kobayakawa, Sløk & Vartia, 2006; Hanley, Liu & Vaona, 2011; Hsu, Tian & Xu, 2014; Laeven, Levine & Michalopoulos, 2015; OECD, 2005b); quality of life (Tellis, Eisingerich, Chandy & Prabhu, 2008); infrastructural development (Roig-Tierno, Alcazar & Ribeiro-Navarrete, 2015; Sohag, Begum, Abdullah & Jaafar, 2015); employment (Dachs & Peters, 2014; Kirchhoff, 1994); and openness to trade (Mandel, 2009; Navas, 2015). Many of these studies have confirmed a positive relationship between innovation[5] and economic growth, both directly and indirectly (for instance, Agenor & Neanidis, 2015; Andergassen, Nardini & Ricottilli, 2009; Audretsch & Feldman, 1996; Bayoumi, Coe & Helpman, 1999; Bottazzi & Peri, 2003; Cameron, 1998; Coe & Helpman, 1995; Francis, Hasan & Wang, 2007; Goel & Ram, 1994; Grliches & Mairesse, 1986; Hasan & Tucci, 2010; Kirchhoff, Catherine, Newbert & Hasan, 2007; Mansfield, 1980; Maurseth & Verspagen, 2002; Santacreu, 2015; Stokey, 1995). However, these studies investigate the relationship between innovation and economic growth without looking at the direction of Granger causality.

The main objective of this paper is to study the Granger causal relationships between innovation and economic growth. It tries to assess the importance of innovation to economic growth, by investigating whether the level of innovation has contributed to economic growth, or whether the expansion of innovation is simply a consequence of rapid economic growth. The empirical investigation has been carried out for European Economic Area (EEA) countries.[6]

The rest of the paper is outlined as follows. The section "*An outline of innovation in the European economic area*" outlines the status of innovation in the EEA countries and the section "*Proposed hypotheses, variables, data and model*" presents the proposed hypotheses, variables, data, and model. The section "*Empirical results and discussion*" presents the empirical results and discussion, and finally, we summarise and conclude the paper in the section "*Conclusion and policy implications*".

An outline of innovation in the European economic area

As described earlier, innovation is widely regarded as an important driver of economic growth (Agenor & Neanidis, 2015; Aghion & Howitt, 2009; Aghion, Akcigit & Howitt, 2013; Fan, 2011). There are two ways we can address the innovation issue. First, by addressing the disparities in innovation activities between countries, and second, by addressing the link between innovation, growth, and economic performance (Howells, 2005). This paper deals with both these issues. However, in this section, we first clarify the use of innovation and then examine its disparity across the EEA countries. In general, innovation can be represented in multiple ways (for instance, Pradhan, Arvin, Hall & Nair, 2016). Nevertheless, we use three types of innovation[7] in this paper. These include the number of patents (residents) per thousand of the population, number of patents (non-residents) per thousand of the population, and total number of patents (both residents and non-residents combined) per thousand of the population. A detailed description of these three innovation indicators is available in Table 1.

This section highlights the innovation trends in EEA countries. Tables 2.1 and 2.2 report the overall status of innovation in EEA countries, both individually and at the aggregate level. Table 2.1 illustrates the status of innovation on an absolute scale (i.e., in terms of number of patents), while Table 2.2 illustrates the status of innovation on a relative scale (i.e., in terms of number of patents per thousand of population). In both these cases, the status of innovation (patents by residents (PAR), patents by non-residents (PAN), and patents by both residents and non-residents combined (PAT); in EEA countries are observed along four different time periods from 1989 to 2014[8] (Tables 2.1 and 2.2). These include P1: 1989- 2000, P2: 2001–2007, P3: 2008–2014, and P4: 1989–2014. From Table 2.1, we outline the following:

First, the number of patents by residents is fairly high in comparison to the number of patents by non-residents. This is true for most of the countries and for all the time periods.
Second, the volume of PAR is the highest in Germany, France, the United Kingdom, and Italy, while it is low in Belgium, the Czech Republic, Greece, and Portugal. This is true for all the four time periods.
Third, the volume of PAN is the highest in Germany, the United Kingdom, France, and Norway, while it is low in Belgium, Greece, Portugal, and Romania. This is again true for all the four time periods.
Fourth, the volume of PAT is the highest in Germany, the United Kingdom, France, and Italy, while it is low in Belgium, Greece, Portugal, and Ireland. This is considerably true for all the time periods.

From Table 2.2, we outline the following:

First, PAR is fairly high in comparison to PAN. This is true for most of the countries except Norway, and for all the four time periods. In case of Norway, the volume of PAN is much higher than PAR.
Second, PAR is comparatively higher in Germany, Finland and Sweden, while it is considerably low in Portugal, Greece and Belgium. This is true for all the four time periods.
Third, PAN is noticeably high in Norway, Finland and the Czech Republic, while it is low in Greece, Portugal, Romania and Spain. This is again true for all the four time periods.

[5] The measurement of innovation varies from study to study (for instance, Griliches, 1990, 1992; Hasan & Tucci, 2010; Hsu et al., 2015; Raymond & St-Pierre, 2010). The common measurements of innovation are patenting activities such as the number of patents by residents and the number of patents by non-residents. We elaborate these measures of innovation in the second section of the paper.

[6] Appendix B provides an appropriate explanation for this sample selection.

[7] The choice of these three types of innovation/indicators are with respect to data availability for EEA countries.

[8] The choice of these time periods is as per data availability only.

Table 1 Definition of variables.

Variables code	Variables definition
GDP	**Per capita economic growth:** Expansion of a country's economy, expressed as a percentage change in per capita gross domestic product.
PAR	**Patents filed by residents:** Patent applications are worldwide patent applications filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for an invention – a product or process that provides a new way of doing something or offers a new technical solution to a problem. A patent provides protection for the invention to the owner of the patent for a limited period, generally 20 years. (Expressed in numbers and used per thousand of population)
PAN	**Patents filed by non-residents:** Patent applications are worldwide patent applications filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for an invention – a product or process that provides a new way of doing something or offers a new technical solution to a problem. A patent provides protection for the invention to the owner of the patent for a limited period, generally 20 years. (Expressed in numbers and used per thousand of population)
PAT	**Patents total (filed by both residents and non-residents):** Patent applications are worldwide patent applications filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for an invention – a product or process that provides a new way of doing something or offers a new technical solution to a problem. A patent provides protection for the invention to the owner of the patent for a limited period, generally 20 years. (Expressed in numbers and used per thousand of population)

Note: Variables above are as defined in the *World Development Indicators of World Bank*.

Fourth, the volume of PAT is the highest in Norway, Germany, Finland and the United Kingdom, while it is low in Greece, Portugal and Romania. This is strikingly true for all the time periods.

In sum, for all the innovation indicators and all the time periods, the coverage of innovation is relatively low in Greece, Portugal and Romania, and substantially high in Germany, Finland and Norway. Additionally, vast regional disparities have been observed between these two groups.

Proposed hypotheses, variables, data and model

In this study, we intend to test the evidence of Granger causal relationship between innovation and per capita economic growth using a sample of 19 EEA countries over the period 1989–2014. We also use cointegration test to detect whether innovation and per capita economic growth are cointegrated; that is, whether there is a long-run equilibrium relationship between these two variables.

Fig. 1 depicts the possible patterns of causal relations between innovation and per capita economic growth. The study intends to test the following hypotheses:

H_1: Innovation (INN) in any year Granger-causes per capita economic growth. This is termed the supply-leading hypothesis of INN- economic growth nexus.
H_2: Per capita economic growth in any year Granger-causes innovation. This is termed the demand-following hypothesis of INN- economic growth nexus.

The novelty of this study is two-fold: (a) we use a large sample of countries, from the European Union, over a recent span of time (1989–2014); and (b) we deploy sophisticated econometrics tools—and certain empirical approaches little used in the literature—to answer questions concerning the nature of Granger causal relationships[9] between innovation and economic growth, both in the short-run and the long-run.

To test these hypotheses, we use the following two variables: per capita economic growth (variable: GDP[10]) and innovation (INN). However, INN is used here in four different forms[11]: number of patents (residents) per thousand of population (variable: PAR), number of patents (non-residents) per thousand of population (variable: PAN), total number of patents (both residents and non-residents combined) per thousand of population (variable: PAT), and researchers in research and development (R&D) activities (variable: RRD) per thousand of population. Table 1 reports on these variables in detail, while Table 3 reports the descriptive statistics of these variables (GDP, PAR, PAN, and PAT) and their correlation matrix (between GDP and three innovation indicators).[12]

Above all, the correlation matrix illustrates that innovation has a positive impact on per capita economic growth, irrespective of any individual indicators (such as PAR, PAN, and PAT) and any country in the EEA group. However, the main observation that we would like to investigate in this

[9] The relationships can be addressed in four different ways: supply-leading approach of innovation-growth nexus, where innovation Granger-causes per capita economic growth; demand-following approach of innovation-growth nexus, where it is the per capita economic growth that Granger-causes innovation; feedback approach of innovation-growth nexus, where both innovation and per capita economic growth Granger-cause each other; and neutrality approach of innovation-growth nexus, where innovation and per capita economic growth are independent of each other.
[10] GDP represents the level of economic growth.
[11] The four different forms can bring four cases for investing the innovation-growth nexus. The first three cases (PAR, PAN, and PAT) represent the output types of innovation, while RRD represents the input type of innovation.
[12] The descriptive statistics of RRD and its correlation with GDP is not available here in order to conserve space.

Table 2.1 Trends of innovation (in numbers) in European Economic Area countries.

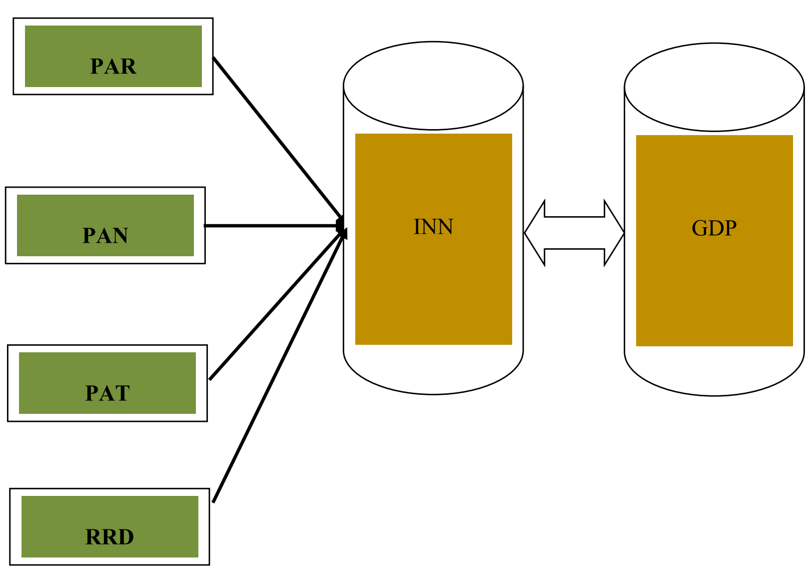
	PAR				PAN				PAT			
Countries	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
Austria	1999	2149	2260	2104	500.7	284.6	280.7	387.4	2499	2433	2540	2491
Belgium	694.5	523.7	661.6	638.8	429.1	164.2	139.3	285.4	1123	687.9	800.9	924.2
Czech Republic	655.4	612.1	833.8	691.9	3349	1918	115.3	1948	4004	2530	949.1	2637
Denmark	1319	1720	1516	1478	732.2	171.1	181.2	442.9	2051	1891	1697	1921
Finland	2234	1997.8	1713	2043	1891	220.4	128.3	1000	4125	2218	1841	3043
France	12,880	14,048	14,565	13,661	3710	3064	1929	3102	16,590	17,112	16,494	16,763
Germany	39,390	48,297	47,517	43,835 8902	11,441	13,348	10,680	48,292	59,738	60,865	54,515	
Greece	254.1	443.1	683.5	410.2	156.1	30.00	22.50	88.76	410.2	473.1	706.0	498.9
Hungary	1333	768.1	680.8	1018	1839	2337	55.67	1550	3172	3105	736.5	2568
Ireland	828.5	865.2	648.5	795.5	1228	86.14	62.50	628.8	2056	951.3	711.0	1424
Italy	7348	9255	8636	8089	942	870.1	885.5	910.5	8290	10,125	9521	8999
Netherlands	2126	2167	2466	2219	615.9	528.7	321.2	520.7	2741	2696	2787	2740
Norway	1118	1153	1124	1129	4549	4958	1532	3939	5667	6111	2656	5068
Poland	2959	2248	3519	2894	2262	3360	237.1	2084	5221	5608	3756	4978
Portugal	87.08	153.9	548.3	216.4	1020	46.14	39.83	512.4	1108	200.1	588.1	728.8
Romania	1988	997.3	1145	1508	474.5	188.8	42.67	290.8	2462	1186	1187	1799
Spain	2235	2913	3419	2709	736.9	344.6	215.8	502.0	2972	3258	3645	3211
Sweden	3744	2938	2259.2	3162.	843.6	512.1	295.0	619.1	4587	3450	2554	3781
United Kingdom	19,324	19,191	15,613	18,396	9235	9939	7087	8917	28,559	29,130	22,700	27,313
EEA#	102,516	112,440	109,808	106,998	43,416	40,464	26,918	38,408	145,932	152,904	136,727	145,406

Note 1: PAR is the number of patents by residents; PAN is the number of patents by non-residents; PAT is the number of patents by both residents and non-residents combined; and EEA is European Economic Area.
Note 2: P1 is 1989–2000; P2 is 2001–2007; P3 is 2008–2014; and P4 is 1989–2014.
Note 3: **#** indicates the figures are average of all 19 EEA countries.

Table 2.2 Trends of innovation (per thousand of population) in European Economic Area countries.

	PAR				PAN				PAT			
Countries	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	0.32	0.30	0.30	0.31
Belgium	0.07	0.05	0.06	0.06	0.04	0.02	0.01	0.03	0.11	0.07	0.07	0.09
Czech Republic	0.06	0.06	0.08	0.07	0.33	0.19	0.01	0.19	0.39	0.25	0.09	0.26
Denmark	0.25	0.32	0.27	0.28	0.14	0.03	0.03	0.08	0.39	0.35	0.31	0.36
Finland	0.44	0.38	0.32	0.39	0.38	0.04	0.02	0.20	0.81	0.42	0.34	0.59
France	0.22	0.22	0.22	0.22	0.06	0.05	0.03	0.05	0.28	0.27	0.25	0.27
Germany	0.48	0.59	0.58	0.54	0.11	0.14	0.16	0.13	0.59	0.72	0.75	0.67
Greece	0.02	0.04	0.06	0.04	0.02	0.01	0.01	0.01	0.04	0.04	0.06	0.05
Hungary	0.13	0.08	0.07	0.10	0.18	0.23	0.01	0.15	0.31	0.31	0.07	0.25
Ireland	0.23	0.21	0.14	0.20	0.35	0.02	0.01	0.18	0.56	0.23	0.16	0.38
Italy	0.13	0.16	0.14	0.15	0.01	0.01	0.01	0.15	0.14	0.17	0.16	0.16
Netherlands	0.14	0.13	0.15	0.14	0.04	0.03	0.02	0.03	0.18	0.17	0.17	0.17
Norway	0.26	0.25	0.23	0.25	1.04	1.08	0.32	0.88	1.30	1.33	0.54	1.13
Poland	0.08	0.06	0.09	0.08	0.06	0.09	0.01	0.05	0.14	0.15	0.10	0.13
Portugal	0.01	0.01	0.05	0.02	0.10	0.01	0.01	0.05	0.11	0.02	0.05	0.07
Romania	0.09	0.05	0.06	0.07	0.02	0.01	0.01	0.01	0.11	0.06	0.06	0.08
Spain	0.06	0.07	0.07	0.06	0.02	0.01	0.01	0.01	0.08	0.08	0.08	0.08
Sweden	0.43	0.33	0.24	0.35	0.10	0.06	0.03	0.07	0.52	0.38	0.27	0.42
United Kingdom	0.33	0.32	0.25	0.31	0.16	0.17	0.19	0.15	0.49	0.49	0.36	0.15
EEA#	3.68	3.59	3.35	3.59	3.22	2.23	0.93	2.47	6.87	5.81	4.19	5.62

Note 1: PAR is the number of patents by residents; PAN is the number of patents by non-residents; PAT is the number of patents by both residents and non-residents combined; and EEA is European Economic Area.
Note 2: P1 is 1989-2000; P2 is 2001-2007; P3 is 2008-2014; and P4 is 1989-2014.
Note 3: # indicates the figures are average of all 19 EEA countries.



Note 1: *GDP* is per capita economic growth; and *INN* is innovation and used as a proxy for PAR, PAN, PAT, and RRD.

Note 2: PAR is the number of patents by residents; PAN is the number of patents by non-residents; PAT is the total patents (by both residents and non-residents combined), and RRD is the researchers in research and development activities.

FIGURE 1 Conceptual framework of the causality between innovation and per capita economic growth.

Table 3 Descriptive statistics and correlations on the variables.

	Variables				Correlation with GDP		
Countries	PAR	PAN	PAT	GDP	PAR	PAN	PAT
Austria	−0.59/0.03	−1.35/0.17	−0.51/0.04	0.87/0.14	0.14**	0.29*	0.21*
Belgium	−1.22/0.07	−1.64/0.27	−1.07/0.12	0.85/0.12	0.10**	0.24*	0.12*
Czech Republic	−1.18/0.07	−1.11/0.71	−0.70/0.34	0.87/0.28	0.38*	0.30*	0.33*
Denmark	−0.56/0.07	−1.36/0.36	−0.47/0.13	0.81/0.27	0.02	0.11**	0.06
Finland	−0.41/0.07	−1.10/0.55	−0.27/0.19	0.89/−1.59	0.34*	0.22*	0.16*
France	−0.66/1.01	−1.32/0.14	−0.57/0.02	0.84/0.11	0.10**	0.57*	0.71*
Germany	−0.28/0.07	−0.89/0.10	−0.18/0.07	0.84/0.24	0.16**	0.10*	0.14*
Greece	−1.48/0.17	−2.32/0.46	−1.37/0.13	0.81/0.29	0.49*	0.16*	0.56*
Hungary	−1.10/0.09	−1.21/0.73	−0.74/0.33	0.90/0.14	0.48*	0.30*	0.25*
Ireland	0.71/0.14	−1.35/0.64	−0.54/0.31	0.95/0.22	0.40*	0.29*	0.30*
Italy	−0.86/0.04	−1.84/0.17	−0.81/0.03	0.63/0.53	0.27*	0.01	0.24*
Netherlands	−0.86/0.05	−1.51/0.14	−0.77/0.04	0.86/0.15	0.02	0.54*	0.29*
Norway	−0.61/0.05	−0.14/0.34	0.02/0.22	0.87/0.12	0.83*	0.47*	0.49*
Poland	−1.16/0.09	−1.50/0.55	−0.91/0.15	1.00/0.08	0.36*	0.11**	0.18*
Portugal	−1.82/0.33	−1.99/0.67	−1.43/0.45	0.84/0.18	0.66*	0.49*	0.10**
Romania	−1.24/0.13	−2.07/0.47	−1.16/0.15	0.81/0.55	0.57*	0.38*	0.61*
Spain	−1.19/0.06	−2.01/0.28	−1.12/0.05	0.84/0.18	0.51*	0.61*	0.10**
Sweden	−0.46/0.12	−1.21/0.25	−0.39/0.13	0.76/0.58	0.30*	0.12**	0.27*
United Kingdom	−0.52/0.06	−0.83/0.09	−0.35/0.07	0.85/0.20	0.40*	0.55*	0.48*
EEA#	−0.88/0.42	−1.46/0.62	−0.72/0.44	0.86/0.31	0.10*	0.02	0.03

Note 1: PAR is the number of patents by residents; PAN is the number of patents by non-residents; PAT is the number of patents by both residents and non-residents combined; GDP is per capita economic growth; and EEA is European Economic Area.
Note 2: the first value represents the mean of the variables, while the second value represents the standard deviation of the variables.
Note 3: * is statistical significance at 1% level; and ** is statistical significance at 5% level.
Note 4: Values reported here are the natural logs of the variables.
Note 5: # indicates the figures are average of all 19 EEA countries.

paper is whether innovation actually causes per capita economic growth, or it is the per capita economic growth that determines the level of innovation in EEA countries. The subsequent section makes an attempt to investigate this issue.

Annual data extending from 1989 to 2014 for the 19 EEA countries[13] were obtained from the *World Development Indicators* of the World Bank. The study uses the following regression model to trace the long-run and short-run causal relationship between innovation and per capita economic growth.

$$Per\ Capita\ Economic\ Grwoth_{it} = \delta_{0Per\ Capita\ Economic\ Growthit} + \delta_{1Per\ Capita\ Economic\ Growthi} Innovation_{it} + \varepsilon_{it} \quad (1)$$

where innovation is used at three different levels such as PAR, PAN and PAT (see Table 1 for details).

$i = 1, 2, \ldots N$ represents an individual country in the EEA panel;
$t = 1, 2, \ldots. T$ refers to the time period (1989–2014); and
ε_{it} is an independently and normally distributed random error with a zero mean and a finite heterogeneous variance (σ_i^2).

Other variations of Eq. (1) are also entertained to change the dependent variable from per capita economic growth to innovation indicators. When we carry out individual country analysis, the subscript '*i*' can be removed from Eq. (1). The parameter $\delta_{1Per\ Capita\ Economic\ Growth}$ signifies long-run elasticity estimates of per capita economic growth with respect to innovation (PAR/ PAN/ PAT/ RRD). The task is to estimate the parameters in Eq. (1) and conduct tests on the Granger causal relationships between these two variables (GDP and INN). We expect that $\delta_{1Per\ Capita\ Economic\ Growth} > 0$, which suggests that an increase in innovation is likely to cause an increase in per capita economic growth.

The Granger causality (GC) test is further applied to know the direction of causality between innovation and per capita economic growth. We use GC test differently for individual country analysis and in the panel setting. The simple GC model (Granger, 1988) is used for individual country analysis, while panel vector autoregressive (VAR[14]) model is deployed for the panel setting.

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

[14] The VAR model follows the estimation process of Holtz-Eakin, Newey & Rosen (1988).

The following VAR models are used to detect the Granger causal relationships between innovation and per capita economic growth:

Model 1: For individual country analysis

$$\begin{bmatrix} \Delta Per\ Capita\ Economic\ Growth_t \\ \Delta Innovation_t \end{bmatrix} = \begin{bmatrix} \delta_{01} \\ \delta_{02} \end{bmatrix} + \sum_{k=1}^{p} \begin{bmatrix} \delta_{11k}(L)\delta_{12k}(L) \\ \delta_{21k}(L)\delta_{22k}(L) \end{bmatrix} \begin{bmatrix} \Delta Per\ Capita\ Economic\ Growth_{t-k} \\ \Delta Innovation_{t-k} \end{bmatrix} + \begin{bmatrix} \eta_{11}ECT_{1t-1} \\ \eta_{21}ECT_{2t-1} \end{bmatrix} + \begin{bmatrix} \xi_{11t} \\ \xi_{21t} \end{bmatrix} \quad (2)$$

The testable hypotheses are as follows:

$H_0 : \delta_{12k=0}$; and $\eta_{11k} = 0$ for $k = 1, 2, \ldots, p$
$H_A : \delta_{12k\,\#0}$; and $\eta_{11k}\ \#0$ for $k = 1, 2, \ldots, p$
$H_0 : \delta_{21k=0}$; and $\eta_{21k} = 0$ for $k = 1, 2, \ldots, p$
$H_A : \delta_{21k\,\#0}$; and $\eta_{21k}\ \#0$ for $k = 1, 2, \ldots, p$

where

ECT is error correction term, which is derived from the long-run cointegration equation;
p is the lag length for the estimation;
Δ is the first difference operator; and
ε_{it} (for $i = 1$ and 2) is an independently and normally distributed random error with a zero mean and a finite heterogeneous variance (σ_i^2).

Model 2: For panel data analysis

$$\begin{bmatrix} \Delta Per\ Capita\ Economic\ Growth_{it} \\ \Delta Innovation_{it} \end{bmatrix} = \begin{bmatrix} \mu_{01j} \\ \mu_{02j} \end{bmatrix} + \sum_{k=1}^{p} \begin{bmatrix} \delta_{11ik}(L)\delta_{12ik}(L) \\ \delta_{21ik}(L)\delta_{22ik}(L) \end{bmatrix} \begin{bmatrix} \Delta Per\ Capita\ Economic\ Growth_{it-k} \\ \Delta Innovation_{it-k} \end{bmatrix} + \begin{bmatrix} \eta_{11i}ECT_{it-1} \\ \eta_{21i}ECT_{it-1} \end{bmatrix} + \begin{bmatrix} \xi_{11it} \\ \xi_{21it} \end{bmatrix} \quad (3)$$

The testable hypotheses are as follows:

$H_0 : \delta_{12ik=0}$; and $\eta_{11ik} = 0$ for $k = 1, 2, \ldots, p$
$H_A : \delta_{12ik\,\#0}$; and $\eta_{11ik}\ \#0$ for $k = 1, 2, \ldots, p$
$H_0 : \delta_{21ik=0}$; and $\eta_{21ik} = 0$ for $k = 1, 2, \ldots, p$
$H_A : \delta_{21ik\,\#0}$; and $\eta_{21ik}\ \#0$ for $k = 1, 2, \ldots, p$

where,

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

This study uses AIC[15] statistics to select the optimum lag length. Moreover, the choice of a particular set of models 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, to know the order of integration and the presence of cointegrating relationship between innovation and per capita economic growth.

Augmented Dickey Fuller unit root test (ADF: Dickey & Fuller, 1981) is used for individual country analysis, while ADF – Fisher chi-square panel unit root test (ADFFC: Maddala & Wu, 1999) is used for the panel setting. In contrast, Johansen (1988) cointegration test is deployed for individual country analysis, while Fisher/Maddala cointegration test (Fisher, 1932; Maddala & Wu, 1999) is deployed at the panel setting. The details of these two unit root tests (unit root and cointegration) are not presented here due to space constraints and are available with the authors on request.

Empirical results and discussion

The Granger causality tests are used to examine the causal relationships between innovation (INN[16]) and per capita economic growth. A necessary step for this test is to know the order of integration[17] of the time series variables and their cointegrating[18] relationships. The discussion begins with the stationarity issue. Using unit root (ADF test at each of the individual countries and ADFFC at the panel setting), we reject the null hypothesis of unit root at the first difference but not for the levels. Table 4 presents these unit root test results, both for individual country and at the panel level. The results indicate that innovation (INN: PAR, PAN, PAT, and RRD[19]) 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 EEA countries, both at individual country level and at the panel setting. The findings suggest that both innovation and per capita economic growth are integrated of order one (i.e., I [1]), which opens the possibility of cointegration between the two (innovation and per capita economic growth).

In the subsequent step, we use 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 possibility of cointegration between innovation and per capita economic growth. The results of both the test statistics are reported in Tables 5 and 6. Table 5 reports λ_{Tra} and λ_{Max} test statistics, while Table 6 reports the summary of cointegration test. These results indicate that innovation and per capita economic growth are cointegrated in some countries,[20] while the cointegration is non-existent in other countries.[21] In sum, the cointegration between innovation and per capita economic growth varies from case to case (for PAR, PAN, PAT, and RRD), and country to country (Tables 5 and C.1, Appendix C).

The presence of cointegration implies that there is a long-run relationship between innovation and per capita

[15] AIC stands for Akaike information criterion and is considered as the best for the optimum lag selection (see, for instance, Billah, King, Snyder & Koehler, 2006; Engle and Yoo, 1987).

[16] INN is a representative for three innovation indicators such as PAR, PAN, and PAT. These variables are defined in Table 1.

[17] The accurate number of differencing where a particular time series variable reaches stationary is called the order of integration (see, for instance, Hamilton, 1994).

[18] When the two-time series variables are non-stationary in their levels and integrated of order one, they can be cointegrated as well, provided there is at least one linear combination among these two variables and that is stationary (see, for instance, Engle & Granger, 1987; Engle Yoo, 1987; Granger, 1986).

[19] The unit root test results of RRD are available in Table C.1 (see Appendix C).

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

[21] These include the Czech Republic, Denmark, Greece, Hungary, Ireland, Italy, Norway, Poland, Portugal, Spain, and the United Kingdom.

Table 4 Results of unit root test.

Countries	Variables PAR	PAN	PAT	GDP
	LD/ FD	LD/ FD	LD/ FD	LD/ FD
Austria	0.14/−5.40*	1.82/−7.46*	0.90/−5.74*	−0.74/−5.64*
Belgium	0.05/−4.65*	1.06/−5.90*	0.91/−4.83*	−0.54/−5.84*
Czech Republic	−0.23/−2.33**	0.52/−2.36**	−0.13/−2.41**	−0.82/−6.61*
Denmark	−0.40/−5.90*	0.62/−6.66*	0.25/−3.37*	−0.68/−7.68*
Finland	1.02/−4.07*	0.92/−3.91*	0.77/−1.02***	−0.55/−3.50*
France	−0.31/−5.96*	0.63/−2.90*	1.24/−4.76*	−0.74/−5.73*
Germany	−2.11/−2.42*	−1.20/−3.09*	−2.43/−2.41*	−1.16/−4.60*
Greece	−2.06/−5.36*	1.23/−5.27*	−0.11/−5.51*	−0.80/−3.63*
Hungary	1.63/−2.95*	0.73/−3.52*	0.59/−3.30*	−1.39/−4.71*
Ireland	1.89/−2.83*	0.69/−3.75*	1.19/−2.49*	−0.80/−3.12*
Italy	0.15/−3.03*	−0.95/−4.40*	−0.60/−3.42*	−0.94/−6.04*
Netherlands	0.04/−4.52*	0.89/−3.21*	0.43/−4.39*	−0.65/−5.87*
Norway	0.17/−6.18*	−0.70/−2.83*	−1.26/−2.72*	−0.23/−5.89*
Poland	0.22/−3.34*	0.47/−3.75*	0.01/−4.11*	−0.33/−5.20*
Portugal	−1.81/−4.23*	0.71/−3.88*	0.15/−2.64*	−1.10/−5.81*
Romania	0.80/−4.87*	0.47/−4.10*	0.91/−4.86*	1.58/−4.83*
Spain	−0.78/−5.21*	2.30/−4.59*	1.11/−5.42*	−0.67/−6.30*
Sweden	1.08/−3.28*	1.53/−5.36*	0.74/−2.65*	−2.32/−7.96*
United Kingdom	0.90/−2.25**	−0.08/−2.32**	0.41/−2.10**	−0.69/−6.83*
EEA[#]	50.5/136.7*	14.8/129.1*	40.6/130.6*	34.2/197.5*

Note 1: PAR is the number of patents by residents; PAN is the number of patents by non-residents; PAT is the number of patents by both residents and non-residents combined; GDP is per capita economic growth; and EEA is European Economic Area.
Note 2: 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 presents the ADF statistics at no trend and no intercept.
Note 3: ADF is Augmented Dickey Fuller test statistics; LD is level data, and FD is first difference data.
Note 4: * is statistical significance at 1% level; and ** is statistical significance at 5% level.
Note 5: # indicates the figures are average of all 19 EEA countries.

Table 5 Results of Johansen–Juselius cointegration test.

Countries	Cointegration with GDP: λ- max test ($r=0/\ r=1\ r\leq1/\ r=2$) PAR	PAN	PAT	λ-Trace test ($r=0/\ r=1\ r\leq1/\ r=2$) PAR	PAN	PAT
Austria	14.5*/4.55*	15.9/*7.73*	15.9*/6.01*	19.6/*4.55*	21.2*/7.30*	19.0*/6.00*
Belgium	28.8*/1.95	8.97/2.87	16.0/* 2.64	30.7*/1.95	11.8/2.87	18.7*/2.64
Czech Republic	9.93/0.07	12.3/0.48	11.7/ 1.77	9.99/0.07	12.8/0.48	13.5/1.77
Denmark	9.43/1.55	36.6*/7.46*	23.4*/8.13*	10.9/1.55	44.1*/7.46*	31.5*/8.13*
Finland	13.5/0.11	17.1*/5.76*	12.3/1.76	13.6/0.11	22.9*/5.76*	14.0/1.76
France	18.8*/3.53	22.0*/0.97	22.2*/ 1.44	18.3*/ 3.43	23.1*/ 0.97	23.6*/1.44
Germany	16.4*/7.96*	15.4*/0.81	16.2*/4.92*	24.3/*7.96*	16.2*/ 0.81	21.1/*4.92*
Greece	9.43/0.01	10.9/1.17	9.49/0.72	9.43/0.01	12.0/1.17	10.2/0.72
Hungary	11.4/3.60	18.96*/2.89	18.8*/2.19	14.9/3.60	21.9*/2.89	21.0*/2.19
Ireland	5.78/0.14	10.2/0.18	12.9/0.26	5.92/0.14	10.4/0.18	13.3/0.26
Italy	-/-	-/-	-/-	-/-	-/-	-/-
Netherlands	8.80/ 3.55	20.5*/5.00*	22.93*/8.66*	14.4/3.55	20.5*/5.00*	21.6/8.66*
Norway	14.7*/3.25	13.4/0.04	16.1*/0.09	17.9*/3.26	13.45/0.04	16.2*/0.09
Poland	12.2/0.04	8.28/0.58	7.59/3.02	12.2/0.04	8.28/0.58	11.6/3.02
Portugal	14.8*/0.46	8.83/3.38	14.7*/1.95	15.3*/0.46	14.2/3.38	16.6*/1.95
Romania	10.10/4.31	8.50/0.45	10.75/2.14	14.4/3.31	8.95/0.45	12.9/2.14
Spain	13.3/1.53	10.05/1.61	9.29/3.82	14.9/1.53	11.66/1.61	15.1/3.82
Sweden	15.7*/0.44	12.3/0.03	13.62/0.24	16.2*/0.44	12.36/0.03	13.87/0.24
United Kingdom	11.57/0.26	17.6*/3.83	15.1*/0.79	11.83/0.26	21.4*/3.83	15.9*/0.79
EEA[#]	107.9*/77.8*	104.5*/58.6*	110.1*/77.6*	128.3*/77.8*	112.2*/58.6*	128.8*/77.5*

Note 1: GDP is per capita economic growth; PAR is the number of patents by residents; PAN is the number of patents by non-residents; PAT is the total number of patents (both by residents and non-residents combined), and EEA is European Economic Area.
Note 2: r represents number of cointegrating vector.
Note 4: We observe statistical significance at 5% level.
Note 5: For Cointegration, the first values represent the figure for $r=0/r=1$, while the second value represents the figure for $r\leq1/\ r=2$.
Note 6: '*' indicates the statistical significance of the cointegrating vector and confines the presence of cointegration between innovation and per capita economic growth.
Note 7: # indicates the figures are average of all 19 EEA countries.

Table 6 Summary of cointegration test results.

Cointegrated			Not cointegrated		
Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Austria (2)	Austria (2)	Austria (2)			
Belgium (1)			Belgium (1)		Belgium (0)
			Czech Republic (0)	Czech Republic (0)	Czech Republic (0)
	Denmark (1)	Denmark (1)	Denmark (0)		
	Finland (1)		Finland (0)		Finland (0)
France (1)	France (1)	France (1)			
Germany (1)	Germany (1)	Germany (1)	Greece (0)	Greece (0)	Greece (0)
	Hungary (1)	Hungary (1)	Hungary (0)		
			Ireland (0)	Ireland (0)	Ireland (0)
			Italy (0)	Italy (0)	Italy (0)
	Netherlands (2)	Netherlands (2)	Netherlands (0)		
Norway (1)		Norway (1)		Norway (0)	
			Poland (0)	Poland (0)	Poland (0)
Portugal (1)		Portugal (1)		Portugal (0)	
			Romania (0)	Romania (0)	Romania (0)
			Spain (0)	Spain (0)	Spain (0)
Sweden (1)				Sweden (1)	Sweden (1)
	United Kingdom (1)	United Kingdom (1)	United Kingdom (0)		
EEA# (2)	EEA# (2)	EEA# (2)			

Note 1: Case 1: cointegration between *PAR* and GDP; Case 2: cointegration between *PAN* and GDP; and Case 3: cointegration between *PAT* and GDP.
Note 2: GDP is per capita economic growth; PAR is the number of patents by residents; PAN is the number of patents by non-residents; PAT is the total number of patents (by both residents and non-residents combined), and EEA is European Economic Area.
Note 3: 0 stands for absence of cointegration between innovation (PAR/ PAN/ PAT) and economic growth, 1 stands for presence of one cointegrating vector between innovation (PAR/ PAN/ PAT) and economic growth, and 2 stands for presence of two cointegrating vectors between innovation (PAR/ PAN/ PAT) and economic growth.
Note 4: Parentheses indicate the number of cointegrating vector (s).
Note 5: Results are derived on the basis of Table 5 results.
Note 6: **#** indicates the figures are average of all 19 EEA countries.

Table 7 Results of test from the error correction model for long-run causality.

	Granger causality test between					
	PAR and GDP		PAN and GDP		PAT and GDP	
Countries	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Austria	4.90*/4.16*	−3.39*/−1.33	8.97*/2.90	−1.79/1.03	0.65/4.82*	−1.16/−1.56
Belgium	18.9*/1.21	−2.46/−0.53	3.62**/1.48	−2.12/1.13	5.24*/0.45	−2.11/1.07
Czech Republic	1.62/4.35*	NA/NA	3.27**/0.74	NA/NA	7.53*/2.16	NA/NA
Denmark	0.42/4.32**	NA/NA	3.16**/9.69*	−1.83/−3.21**	0.87/10.6*	−0.59/3.72
Finland	4.32*/0.31	NA/NA	0.57/ 5.29*	−1.20/ 2.03	3.76***/7.90*	−4.36*/−1.84
France	3.19**/ 0.60	−2.83/ −1.12	13.8*/2.57	2.91/ −1.41	6.89*/2.56	−4.36*/ −1.84
Germany	3.34**/1.01	−3.27*/−0.82	0.72/ 12.2*	−4.03*/2.92***	0.91/7.49*	−3.64*/−2.57
Greece	6.73*/0.12	NA/NA	1.09/8.64*	NA/NA	11.2*/13.8*	NA/NA
Hungary	1.51/5.58*	NA/NA	4.50*/5.28*	−2.03/−1.57	0.98/1.83	0.44/2.10
Ireland	0.63/3.95*	NA/NA	3.25**/5.63*	NA/NA	3.85*/6.54*	NA/NA
Italy	6.74*/0.71	NA/NA	0.49/1.87	NA/NA	3.97*/1.12	NA/NA
Netherlands	3.26***/0.90	NA/NA	3.64**/2.23	−2.38/−1.57	3.11***/6.05*	−0.01/4.13
Norway	2.83/14.5*	−0.85/5.06	1.62/23.8*	NA/NA	5.05*/0.66	0.39/2.20
Poland	14.3*/ 5.46*	NA/NA	0.67/ 1.42	NA/NA	2.23/3.40***	NA/NA
Portugal	5.19*/ 1.20	−3.69***/1.28	4.09**/16.8*	NA/NA	2.89/11.5*	−2.5/−3.42*
Romania	5.10*/ 0.86	NA/NA	3.69*/2.07	NA/NA	5.19*/2.33	NA/NA
Spain	4.21**/4.56*	NA/NA	5.42*/0.96	NA/NA	3.53*/0.73	NA/NA
Sweden	8.93*/13.5*	−4.10*/−2.33	7.15*/0.13	NA/NA	3.40***/0.42	NA/NA
United Kingdom	2.99***/0.33	NA/NA	10.1*/3.81***	−4.69*/ −2.97***	5.68*/2.92	−3.92*/−0.21
EEA#	5.91*/10.1*	−6.09*/−2.60	0.45/6.61*	−6.23*/−2.38	1.14/9.71*	−6.08*/−2.49

Note 1: GDP is per capita economic growth; PAR is the number of patents by residents; PAN is the number of patents by non-residents; PAT is the total number of patents (by both residents and non-residents combined), and EEA is European Economic Area.
Note 2: The short-run causality is detected through Wald statistics, while long-run causality is detected through the statistical significance of error correction term.
Note 3: For both short-run and long-run, the first ***v***alues represent GDP as the dependent variable and the second value represents innovation as the dependent variable (PAR/ PAN/ PAT).
Note 4: '*' indicates the statistical significance at 1% level, '**' indicates the statistical significance at 5% level and '***' indicates the statistical significance at 10% level.
Note 5: **#** indicates the figures are average of all 19 EEA countries.

economic growth (Engle & Granger, 1987). On the contrary, the absence of cointegration indicates that there is no long-run relationship between the two variables. The summary of these cointegration test results is reported in Table 6.

For Granger causality detection, we deploy 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 confirmed the existence of cointegration between the two, the next step is to determine the direction of causality between innovation and per capita economic growth. The estimated results of the Granger causality test are reported in Tables 7 and 8.1 and 8.2. Table 7 reports the presence of both short-run and long-run equilibrium relationships between innovation and per capita economic growth, while Tables 8.1 and 8.2 report the summary of short-run Granger causal nexus between these two sets of variables (GDP vs. PAR; GDP vs. PAN; and GDP vs. PAT). The analysis is based on the individual indicators of innovation and per capita economic growth. Coming to long-run equilibrium relationships, we find the presence of cointegration between innovation and economic growth in few cases,[22] while absence in rest of the cases.[23] On the contrary, we have a divergent experience in the context of short-run Granger causality between innovation and per capita economic growth. The results of this section follow.

Case 1: Between innovation (PAR) and per capita economic growth (GDP)

For Belgium, Finland, France, Germany, Greece, Italy, the Netherlands, Portugal, Romania, and the United Kingdom, there is a unidirectional causality from innovation to per capita economic growth (PAR => GDP), whereas for the Czech Republic, Denmark, Hungary, Ireland, and Norway, per capita economic growth Granger-causes innovation (PAR <= GDP). Additionally, for Austria, Poland, Spain, Sweden, and EEA panel, there is bidirectional causality between innovation and per capita economic growth (PAR <=> GDP).

Case 2: Between innovation (PAN) and per capita economic growth

For Austria, Belgium, the 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, per capita economic growth Granger causes innovation (GDP => PAN). Besides, for Denmark, Hungary, Ireland, Portugal, the United Kingdom, and the EEA panel, there is bidirectional causality between innovation and per capita economic growth (PAN ⟨=⟩ GDP), while in the context of Italy, and Poland, per capita economic growth does not Granger-cause innovation (GDP ⟨#⟩ PAN).

[22] These include Austria, Germany, Portugal, Sweden and EEA in Case 1; Denmark, Germany, the United Kingdom and EEA in Case 2; Finland, France, Germany, Portugal, the United Kingdom and EEA in Case 3; and France, Hungary, Poland, Romania, the United Kingdom and EEA in Case 4.

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

Table 8.1 Summary of Granger causality test.

Countries	Nature of Granger causality between PAR and GDP	PAN and GDP	PAT and GDP
Austria	FBH	SLH	DFH
Belgium	SLH	SLH	SLH
Czech Republic	DFH	SLH	SLH
Denmark	DFH	FBH	DFH
Finland	SLH	DFH	FBH
France	SLH	SLH	SLH
Germany	SLH	DFH	DFH
Greece	SLH	DFH	FBH
Hungary	DFH	FBH	NLH
Ireland	DFH	FBH	FBH
Italy	SLH	NLH	SLH
Netherlands	SLH	SLH	FBH
Norway	DFH	DFH	SLH
Poland	FBH	NLH	DFH
Portugal	SLH	FBH	DFH
Romania	SLH	SLH	SLH
Spain	FBH	SLH	SLH
Sweden	FBH	SLH	SLH
United Kingdom	SLH	FBH	SLH
EEA#	FBH	FBH	FBH

Note 1: GDP is per capita economic growth; PAR is the number of patents by residents; PAN is the number of patents by non-residents; PAT is the total patents (by both residents and non-residents combined), and EEA is European Economic Area.
Note 2: SLH indicates unidirectional causality from innovation to economic growth; DFH indicates unidirectional causality from economic growth to innovation; FBH indicates bidirectional causality between innovation and economic growth; and NLH indicates no causal flow between innovation and economic growth.
Note 3: Results are derived on the basis of Table 7 results.
Note 4: # indicates the figures are average of all 19 EEA countries.

Case 3: Between innovation (PAT) and per capita economic growth

For Belgium, the Czech Republic, France, Italy, Norway, Romania, Spain, Sweden, and the United Kingdom, there is a unidirectional causality from innovation to per capita economic growth (PAT => GDP), whereas for Austria, Denmark, Germany, Poland, and Portugal, per capita economic growth Granger-causes innovation (GDP => PAT). Additionally, for Finland, Greece, Ireland, Italy, and EEA panel, there is bidirectional causality between innovation and per capita economic growth (PAT ⟨=⟩ GDP), while in the context of Hungary, per capita economic growth does not Granger-cause innovation (GDP ⟨#⟩ PAT).

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

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

Table 8.2 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		
Finland			Denmark		Denmark
France	France	France		Finland	
Germany				Germany	Germany
Greece				Greece	
Italy	Italy		Hungary		
Netherlands	Netherlands		Ireland		
		Norway	Norway	Norway	
					Poland
Portugal					Portugal
Romania	Romania	Romania			
	Spain	Spain			
	Sweden	Sweden			
United Kingdom		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			Hungary
		Greece			
	Hungary			Italy	
	Ireland	Ireland			
		Netherlands			
Poland					
	Portugal			Poland	
Spain					
Swedeen					
	United Kingdom				
EEA#	EEA#	EEA#			

Note 1: Case 1: cointegration between *PAR* and GDP; Case 2: cointegration between *PAN* and GDP; and Case 3: cointegration between *PAT* and GDP.
Note 2: GDP is per capita economic growth; PAR is the number of patents by residents; PAN is the number of patents by non-residents; PAT is the total patents (by both residents and non-residents combined), and EEA is European Economic Area.
Note 3: Results are derived on the basis of Table 8.1 results.
Note 4: # indicates the figures are average of all 19 EEA countries.

capita economic growth (RRD <==> GDP), while in the context of Greece and Sweden, per capita economic growth does not Granger-cause innovation (RRD ⟨#⟩ GDP). The results of this section are reported in Appendix C (Table C.1).

As is evident from the individual country results,[24] the nature of the causal relationship between innovation and per capita economic growth are more or less country specific and innovation indicator(s)[25] specific. In some cases, innovation Granger-causes per capita economic growth, while in other cases, it is the per capita economic growth that actually Granger-causes innovation. Again, in some cases, they reinforce each other (feedback), while in some other cases, they do not cause each other, i.e., they have independent (neutral) relationship.

Conclusion and policy implications

The performance of innovation should not go unnoticed because it plays an imperative role in stimulating economic growth (Hasan & Tucci, 2010). This study explored the Granger causal nexus between innovation and per capita economic growth for the 19 European Economic Area countries using time series data from 1989 to 2014. The focal message from our study for policy-makers and researchers alike is that implications drawn from research on per capita economic growth that disregards the dynamic interrelation of the two variables will be defective. It is the conjoint back-and-forth relationship between the two variables (per

[24] The used sample size could give some caution for the generalisability of our findings. However, the sample size is a good representative of a few countries and the panel. Additionally, we have conducted a couple of robustness checks for this analysis. We have: (1) used the normalised data of both innovation and per capita economic growth; (2) deployed additional unit root tests (Phillips and Perron (1988) unit root test at the individual country and Im-Pesaran-Shin [Im et al., 2003] unit root test at the panel level) to know the order of integration; (3) deployed additional cointegration tests (Engle & Granger (1987) at individual country and Pedroni (1999) test at the panel level); and (4) tested the VAR/ VECM model by changing the order of lag. Our results are more or less consistent with these robustness checks.

[25] It is with respect to PAR, PAN, PAT, and RRD.

capita economic growth and innovation) that is the highlight of our study and guides future research on this topic.

Our study concedes mixed evidence on the interrelationship between innovation and per capita economic growth in the 19 EEA countries, both at the individual country level and in 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 other instances, it is innovation that determines the level of per capita economic growth, lending support to supply-leading hypothesis of innovation-growth nexus. There are also cases where innovation and per capita economic growth are mutually dependent on each other. In such situations both are self-reinforcing and they offer support to the feedback hypothesis of innovation-growth nexus. In addition, there are also cases where innovation and per capita economic growth are independent of each other. This is the situation where both are neutral and offer support to the 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 bi-directional causality in some instances, policies that increase per capita economic growth (such as actions to increase investment) would be desirable to bring more innovation in the economy. Therefore, it is suggested that the government should play a more positive role in order to foster innovation and integrate it with per capita economic growth.

Undoubtedly, many countries including those in the EEA have recognised the importance of innovation for high economic growth and accordingly, they have increased their efforts to encourage more innovation in their countries. But what is required is that government should pay high attention to bring in a steady economic environment in order to promote the link between innovation and per capita economic growth.

Appendix A. Necessity of linking innovation and economic growth

Since about the time of Schumpeter (1932), the process of industrial innovation seems to be an important factor in economic change. Schumpeter was an early thinker on the relationship between industrial innovation and economic growth at a more macro level. From his point of view, economic change revolves around innovation, entrepreneurship and market power. Innovation, as a determinant of growth, is attractive to much of the empirical research because of its straightforward measurement.

Innovation is fundamental to economic growth. The process through which resources spent in research and development (R&D) generate new ideas, and the process of their diffusion are at the heart of the growth mechanism of modern market economies (see, inter alia, Bottazzi & Peri, 2003). Innovation is considered as one of the key sources of progress (Fagerberg, 1994), and technological innovation has become an essential instrument in any development policy (Trajtenberg, 1990). Innovation is considered as one of the key drivers of an economy (Andergassen et al., 2009; Bae & Yoo, 2015; Mansfield, 1972; Nadiri, 1993; Romer, 1986; Santacreu, 2015; Solow, 1956). It affects the economy in multiple ways , such as economic growth, global competitiveness, financial systems, quality of life, infrastructure development, employment, trade openness, and hence, spawns high economic growth (Pradhan, Arvin, Bahmani & Bennett, 2017; Maradana, Pradhan, Dash, Gaurav, Jayakumar & Chatterjee, 2017).

Over time, due to the popularity of endogenous growth theory, both economists and policy makers increasingly believe that differences in innovation capacity are largely responsible for large differences in development levels of individual economies (Grossman & Helpman, 1991; Ulku, 2007). By bringing innovation to therefore, it is often assumed that greater investment in basic R&D will lead to greater applied research and to an increase in the number of inventions that, when introduced in the production chain, become growth-enhancing innovations. This linear perception of innovation process places localised R&D investment at the heart of technological progress and, eventually, economic growth.

To understand the relationship between innovation activities and economic growth, some studies draw upon the basic theory of endogenous technical change developed by Romer (1990), Grossman and Helpman (1991), and Aghion et al., 1992. The typical version of this theory contains innovation activities which allow an entrepreneur to produce one of the many intermediate products at a cost temporarily lower than that of rivals. The extent of innovative activities undertaken by society commands the rate of economic growth (Schumpeter, 1912; King & Levine, 1993; Ulku, 2004; Aghion et al., 2005). Extant literature specifies that innovation activities contribute to economic growth, both directly and indirectly, via other macroeconomic factors (Furman, Porter & Stern, 2002; Hassan & Tucci, 2010). But it is possible that innovation activities are also equally affected by economic growth and other macroeconomic factors. The view of innovation as a factor that could be overlooked in the genesis of economic development is now firmly on the retreat.

Appendix B. Why for the EEA region

Europe maintains lofty ambitions to build its growth and prosperity, and to safeguard its social model through innovation. The European Union built this ambition into its 2002 Lisbon Strategy in order to become the most competitive knowledge based economic union in the world. An ambitious target of devoting 3% of growth to research and development by 2010 was set. Again, in its subsequent *Europe 2020 Strategy and Innovation Union Flagship*, it set out a roadmap for sustainable and inclusive growth that needs to be smart (Cincera & Veugelers, 2013; Veugelers & Cincera, 2010).

Between 1980 and 2007, in European countries, significant episodes of economic slowdown occurred more than twice as frequently as significant episodes of growth acceleration. Economic growth in the EU since the onset of the global financial crisis in 2007 has been disappointing (Balcerowicz, Rzónca, Kalina & Laszek, 2013).

"Research and innovation" is one of the core objectives of the Europe 2020 Strategy for Smart, sustainable and inclusive growth (Ciocanel & Pavelescu, 2015). The creation of a *European Economic Area* or *European Research Area*, where researchers and scientific knowledge can circulate freely, is a key factor in European efforts to meet EU 2020 goals. The EFTA Working Group on Research and Innovation follows the EU's science and innovation policy and initiatives, and in particular Horizon 2020, the *EU Framework Programme for Research and Innovation*, which is the financial instrument implementing the Europe 2020 flagship initiative aimed at securing Europe's global competitiveness (Protocol 31, EEA Agreement, Veugelers & Cincera, 2015).

EU Horizon 2020 is a funding programme within the Innovation Union strategy. By improving conditions and access to finance for research and innovation in Europe, it ensures that innovative ideas can be turned into products and services that create growth and jobs. The new Framework Programme Horizon 2020 integrates various EU funding activities for research and innovation, stressing two important aspects. The first emphasis is on the simplification and streamlining of the application and grant procedures, especially through the use of a single set of rules applicable to all funding activities. Additionally, with regard to funding for small and medium-sized enterprises (SMEs), a one stop shop for application, and thus a lower administrative burden for applicants, is intended (Veugelers, 2008).

Appendix C. Granger causality between economic growth and researchers in research and development activities

Table C1.

Table C.1 Results of unit root test, cointegration test and Granger causality test between RRD and GDP.

	Unit root (RRD)	Cointegration		Granger causality	
Countries	LD/ FD	($r = 0/\ r = 1\ r \leq 1/\ r = 2$)		Short-run	Long-run
Austria	−0.67/−3.22*	13.7/3.35	10.3/3.35	3.20**/0.40	NA/NA
Belgium	−0.62/−2.46*	13.8/1.26	12.5/1.26	13.6*/1.19	NA/NA
Czech Republic	−1.31/−2.73*	13.3/0.57	12.7/0.57	5.14*/0.41	NA/NA
Denmark	−0.99/−5.07*	1.9/1.61	10.3/1.61	0.46/5.28*	NA/NA
Finland	0.43/−3.33*	7.43/0.15	7.29/0.15	0.07/25.3*	NA/NA
France	1.02/−5.83*	15.5*/0.20	15.3*/0.20	3.12**/2.12	−2.35/−1.13
Germany	−1.63/−2.28**	11.4/0.78	10.6/0.78	5.31*/0.18	NA/NA
Greece	-/-	-/-	-/-		-/-
Hungary	−1.79/−5.70*	15.0*/0.43	15.0*/0.43	7.12*/0.46	−4.14*/−1.26
Ireland	−3.93/−1.88**	12.5/0.11	12.4/0.11	0.99/3.62**	NA/NA
Italy	−1.13/−3.88*	12.3/0.01	12.3/0.01	4.43*/0.47	NA/NA
Netherlands	−1.54/−4.54*	11.3/0.01	11.3/0.01	1.34/6.33*	NA/NA
Norway	0.10/−1.72**	13.2/2.26	12.9/2.26	0.01/5.86*	NA/NA
Poland	−2.49/−4.00*	14.2*/0.18	14.0*/0.18	0.75/5.68*	−0.86/−1.90
Portugal	−3.54/−1.84**	10.3/0.03	10.3/0.03	9.83*/1.46	NA/NA
Romania	0.82/−4.02*	39.9*/9.95*	29.9*/9.95*	3.84*/3.74*	−7.97*/1.96
Spain	−2.66/−2.66*	20.2*/6.72*	18.5*/6.72*	0.15/6.46*	−0.62/−3.14
Sweden	0.14/−3.80*	10.9/1.19	9.67/1.19	1.45/0.15	NA/NA
United Kingdom	−1.11/−1.50**	19.9*/7.82*	22.0*/7.82*	9.47*/2.25	−0.82/−2.62
EEA#	108.0/95.4*	108.9*/76.37*	88.87*/76.37*	3.03*/2.95*	−6.15*/−1.23

Note 1: RRD is the number of researchers in research and development activities; GDP is per capita gross domestic product; and EEA is European Economic Area.
Note 2: For unit root test, we report here ADF results for RRD only, as GDP results are already reported in Table 4. ADF is Augmented Dickey Fuller test statistics, LD is level data, and FD is first difference data. The first figure is at level data, while the second figure is at first difference (with reference to column 1). 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 presents the ADF statistics at no trend and no intercept.
Note 3: For cointegration test, r represents the number of cointegrating vector. The first value represents the figure for $r = 0/r = 1$, while the second value represents the figure for $r \leq 1/\ r = 2$.
Note 4: For Granger causality test, 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) as the dependent variable.
Note 5: * and ** indicate the statistical significance at 1% and 5% levels, respectively.
Note 6: # indicates the reported statistics are calculated at the panel level.

References

Agenor, P., & Neanidis, K.C. (2015). Innovation, public capital, and growth. *Journal of Macroeconomics* 44, 252–275.

Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (1992). Competition and Innovation: An Inverted-U Relationship. *Quarterly Journal of Economics* 120, 701–728.

Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (2005). Competition and Innovation: An Inverted-U Relationship. *Quarterly Journal of Economics* 120 (2), 701-728.

Aghion, P., Akcigit, U., & Howitt, P. (2013). What do we learn from Schumpeterian growth theory? Working Paper 18824. National Bureau of Economic Research, Cambridge.

Aghion, P., & Howitt, P. (2009). The economics of growth. MIT Press, Cambridge, MA.

Andergassen, R., Nardini, F., & Ricottilli, M. (2009). Innovation and growth through local and global interaction. *Journal of Economic Dynamics and Control* 33 (10), 1779–1795.

Audretsch, D.B., & Feldman, M.P. (1996). R&D spillovers and the geography of innovation and production. *American Economic Review* 86 (3), 630–640.

Bae, S.H., & Yoo, K. (2015). Economic modelling of innovation in the creative industries and its implications. *Technological Forecasting and Social Change* 96, 101–110.

Balcerowicz, L., Rzónca, A., Kalina, L., & Laszek, A. (2013). Economic Growth in the European Union. Lisbon Council E-Book. https://lisboncouncil.net/growth/documents/LISBON_COUNCIL_Economic_Growth_in_the_EU%20(1).pdf.

Bayoumi, T., Coe, D.T., & Helpman, E. (1999). R&D spillovers and global growth. *Journal of International Economics* 47 (2), 399–428.

Billah, B., King, M., Snyder, R., & Koehler, A. (2006). Exceptional smoothing model selection for forecasting. *International Journal of Forecasting* 22 (2), 239–247.

Bottazzi, L., & Peri, G. (2003). Innovation and spillovers in regions: Evidence from European patent data. *European Economic Review* 47 (4), 687–710.

Cameron, G. (1998). Innovation and growth: a survey of the empirical evidence. Nuffield College, Oxford University, Working Paper, Oxford.

Cincera, M., & Veugelers, R. (2013). Young leading innovators and the EU's R&D intensity gap. *Economics of Innovation and New Technology* 22 (2), 177–198.

Ciocanel, A.B., & Pavelescu, F.M. (2015). Innovation and competitiveness in European context. *Procedia Economics and Finance* 32, 728–737.

Coad, A., Segarra, A., & Teruel, M. (2016). Innovation and firm growth: Does firm age play a role. *Research Policy* 45, 387–400.

Coe, D.T., & Helpman, E. (1995). International R&D spillovers. *European Economic Review* 39 (5), 859–887.

Corrado, C., Haskel, J., Jona-Lasinio, C., & Iommi, M. (2013). Innovation and intangible investment in Europe, Japan, and the United States. *Oxford Review of Economic Policy* 29 (2), 261–286.

Dachs, B., & Peters, B. (2014). Innovation, employment growth, and foreign ownership of firms: A European perspective. *Research Policy* 43 (1), 214–232.

de Serres, A., Kobayakawa, S., Sløk, T., & Vartia, L. (2006). *Regulation of Financial Systems and Economic Growth*, OECD Economics Department Working Paper No. 506. OECD, Paris. www.olis.oecd.org/olis/2006doc.nsf/linkto/ECO-WKP*(2006)34*.

Dickey, D.A., & Fuller, W.A. (1981). Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica: Journal of the Econometric Society* 49 (4), 1057–1072.

Engle, R.F., & Granger, C.W.J. (1987). Cointegration and error correction: Representation, estimation and testing. *Econometrica: Journal of the Econometric Society* 55 (2), 251–276.

Engle, R.F., & Yoo, B.S. (1987). Forecasting and testing in co-integrated systems. *Journal of Econometrics* 35 (1), 143–159.

Fan, P. (2011). Innovation capacity and economic development: China and India. *Economic Change and Restructuring* 44 (1-2), 49–73.

Fagerberg, J. (1994). Technology and international differences in growth rates. *Journal of Economic Literature* 32 (3), 1147–1175.

Fisher, R.A. (1932). Statistical methods for research workers, 4th edition Oliver & Boyd, Edinburgh.

Francis, B., Hasan, I., & Wang, H. (2007). The role of venture capital on innovation, new business formation and economic growth. Lally School of Management & Technology, Working Paper, RPI, New York.

Freeman, C., & Soete, L. (1997). The economics of industrial innovation. MIT Press, Cambridge.

Furman, J., Porter, M.E., & Stern, S. (2002). The determinants of national innovative capacity. *Research Policy* 31, 899–933.

Galindo, M., & Mendez, M.T. (2014). Entrepreneurship, economic growth, and innovation: Are feedback effects at work. *Journal of Business Research* 67 (5), 825–829.

Garcia, R., & Calantone, R. (2002). A critical look at technological innovation typology and innovativeness terminology: A literature review. *Journal of Product Innovation Management* 19 (2), 110–132.

Goel, R.K., & Ram, R. (1994). Research and development expenditures and economic growth: A cross-country study. *Economic Development and Cultural Change* 42 (2), 403–411.

Granger, C.W. (1986). Developments in the study of cointegrated economic variables. *Oxford Bulletin of Economics and Statistics* 48 (3), 213–228.

Granger, C.W.J. (1988). Some recent developments in a concept of causality. *Journal of Econometrics* 39 (1–2), 199–211.

Griliches, Z. (1990). Patent statistics as economic indicators: A survey. *Journal of Economic Literature* 28 (4), 1661–1707.

Griliches, Z. (1992). The search for R&D spillovers. *Scandinavian Journal of Economics* 94 (1), 29–47.

Griliches, Z., & Mairesse, J. (1986). R&D and productivity growth: Comparing Japanese and us manufacturing firms. *European Economic Review* 21 (1–2), 89–119.

Grossman, G.M., & Helpman, E. (1994). Endogenous innovation in the theory of growth. *Journal of Economic Perspectives* 8 (1), 23–44.

Grossman, G., & Helpman, E. (1991). Innovation and growth in the global economy. MIT Press, Cambridge, MA.

Grossman, V. (2009). Entrepreneurial innovation and economic growth. *Journal of Macroeconomics* 31 (4), 602–613.

Hamilton, J.D. (1994). Time series analysis. Princeton University Press, Princeton.

Hanley, A., Liu, W., & Vaona, A. (2011). Financial development and innovation in China: Evidence from the provincial data. Kiel Working Paper, No. 1673. Kiel Institute of World Economy, Hindenburgufer.

Hassan, I., & Tucci, C.L. (2010). The innovation-economic growth nexus: Global evidence. *Research Policy* 39 (10), 1264–1276.

Hausman, A., & Johnston, W.J. (2014). The role of innovation in driving the economy: Lessons from the global financial crisis. *Journal of Business Research* 67 (1), 2720–2726.

Holtz-Eakin, D., Newey, W., & Rosen, H.S. (1988). Estimating vector auto regressions with panel data. *Econometrica: Journal of the Econometric Society* 56 (6), 1371–1395.

Howells, J. (2005). Innovation and regional economic development: A matter of perspective. *Research Policy* 34 (8), 1220–1234.

Hsu, C., Lien, Y., & Chen, H. (2015). R&D internationalization and innovation performance. *International Business Review* 24, 187–195.

Hsu, P.H., Tian, X., & Xu, Y. (2014). Financial development and innovation: Cross-country evidence. *Journal of Financial Economics* 112 (1), 116–135.

Huang, K.F. (2011). Technology competencies in competitive environment. *Journal of Business Research* 64 (2), 172–179.

Hudson, J., & Minea, A. (2013). Innovation, intellectual property rights, and economic development: A unified empirical investigation. *World Development* 46 (1), 66-78.

Im, K.S., Pesaran, M.H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics* 115 (1), 53-74.

Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control* 12 (2-3), 231-254.

Kim, J., & Lee, S. (2015). Patent databases for innovation studies: A comparative analysis of USPTO, EPO, JPO and KIPO. *Technological Forecasting and Social Change* 92, 332-345.

King, R.G., & Levine, R. (1993). Finance and growth: Schumpeter might be right. *Quarterly Journal of Economics* 107, 717-737.

Kirchhoff, B.A. (1994). Entrepreneurship and dynamic capitalism: The economics of business firm formation and growth. Praeger, Westport, CT.

Kirchhoff, B., Catherine, A., Newbert, S.L., & Hasan, I. (2007). The influence of university R&D expenditures on new business formations and employment growth. *Entrepreneurship Theory and Practice* 31 (4), 543-559.

Laeven, L., Levine, R., & Michalopoulos, S. (2015). Financial innovation and endogenous growth. *Journal of Financial Intermediation* 24, 1-24.

Maddala, G.S., & Wu, S. (1999). A comparative study of unit roots with panel data a new simple test. *Oxford Bulletin of Economics and Statistics* 61 (4), 631-651.

Mandel, M. (2009). The failed promise of innovation in the U.S. *Businessweek* June 3, 26-34.

Mansfield, E. (1972). Contribution of R&D to economic growth in the United States. *Science* 175 (4021), 477-486.

Mansfield, E. (1980). Basic research and productivity increase in manufacturing. *American Economic Review* 70 (5), 863-873.

Maradana, R., Pradhan, R.P., Dash, S., Jayakumar, M., & Chatterjee, D. (2017). Does Innovation Promote Economic Growth? Evidence from European countries. *Journal of Innovation and Entrepreneurship* 6 (1), 1-23.

Maurseth, P.B., & Verspagen, B. (2002). Knowledge spillovers in Europe: A patent citation analysis. *Scandinavian Journal of Economics* 104 (4), 531-545.

Nadiri, M.I. (1993). Innovations and Technological Spillovers. NBER Working Paper, No. 4423. National Bureau of Economic Research, Cambridge.

Navas, A. (2015). Trade liberalisation and innovation under sector heterogeneity. *Regional Science and Urban Economics* 50, 42-62.

OECD, 2005. Oslo manual: Guidelines for collecting and interpreting innovation data, 3rd edition Organization for Economic Cooperation and Development (OECD), Paris.

OECD, 2005. Economics policy reforms 2005: Going for growth. OECD, Paris.

OECD, 2007. Innovation and growth: Rationale for an innovation strategy. OECD, Paris.

Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics* 61 (4), 653-670.

Petrakis, P.E., Kostis, P.C., & Valsamis, D.G. (2015). Innovation and competitiveness: Culture as a long-term strategic instrument during the european great recession. *Journal of Business Research* 68, 1436-1438.

Phillips, P.C.B., & Perron, P. (1988). Testing for unit roots in time series regression. *Biometrika* 75 (2), 335-346.

Pradhan, R.P., Arvin, M.B., Bahmani, S., & Bennett, S.E. (2017). The innovation- growth link in OECD countries: Could other macroeconomic variables matter. *Technology in Society* 51, 113-123.

Pradhan, R.P., Arvin, M.B., Hall, J.H., & Nair, M. (2016). Innovation, financial development, and economic growth in eurozone countries. *Applied Economics Letters* 23 (6), 1141-1144.

Raymond, L., & St-Pierre, J. (2010). R&D as a determinant of innovation in manufacturing SMEs: An attempt at empirical clarification. *Technovation* 30 (1), 48-56.

Rogers, E. (1995). Diffusion of innovations. Free Press, New York.

Romer, P.M. (1986). Increasing returns and long-run growth. *Journal of Political Economy* 94 (5), 1002-1037.

Romer, P.M. (1990). Endogenous technological change. *Journal of Political Economy* 98 (5), S71-S102.

Roig-Tierno, N., Alcazar, J., & Ribeiro-Navarrete, S. (2015). Use of infrastructures to support innovative entrepreneurship and business growth. *Journal of Business Research* 68, 2290-2294.

Santacreu, A.M. (2015). Innovation, diffusion, and trade: Theory and measurement. *Journal of Monetary Economics* 75, 1-20.

Schumpeter, J.A. (1911). The theory of economic development. Harvard University Press, Cambridge, MA.

Schumpeter, J.A. (1912). The Theory of the Economic Development: An Inquiry into Profits, Capital, Credit, Interest and Business Cycle. Harvard Press, Cambridge.

Schumpeter, J.A. (1932). Capitalism, socialism, and democracy. Harper and Brothers, New York.

Sohag, K., Begum, R.A., Abdullah, S.M.S., & Jaafar, M. (2015). Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia. *Energy* 1-11. doi: 10.1016/j.energy.2015.06.101.

Solow, R.M. (1956). A Contribution to the theory of economic growth. *Quarterly Journal of Economics* 70 (1), 65-94.

Stokey, N.L. (1995). R&D and economic growth. *Review of Economic Studies* 28 (4), 1661-1707.

Tellis, G.J., Eisingerich, A.B., Chandy, R.K., & Prabhu, J.C. (2008). Competing for the future: Patterns in the global location of R&D centers by the world's largest firms. ISBM Report 06-2008. Institute for the Study of Business Markets, University Park, PA.

Trajtenberg, M. (1990). A penny for your quotes: patent citations and the value of innovations. *The RAND Journal of Economics* 21 (1), 172-187.

Ulku, H. (2004). R&D, Innovation, and Economic Growth: An Empirical Analysis. International Monetary Fund, Working Papers, WP/04/185, pp. 2-35.

Ulku, H. (2007). R&D, innovation and output evidence from OECD and non OECD countries. *Applied Economics* 39, 291-307.

Veugelers, R. (2008). The role of SMEs in innovation in the EU: A case for policy intervention. *Review of Business and Economics* 53 (3), 239-262.

Veugelers, R., & Cincera, M. (2010). Europe's missing yollies. Bruegel, Brussels Policy Brief 2010/06.

Veugelers, R., & Cincera, M. (2015). The impact of horizon 2020 on innovation in Europe. *Intereconomics Forum*. doi: 10.1007/s10272-015-0521-7.