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Highlights

- We assess the link between innovation and per capita economic growth.
- We study the causal relationships for the EEA countries during 1989-2014.
- We deploy a panel vector auto-regressive model to detect the direction of causality.
- We find Granger causality between the variables in the short and long run.
- The nature of Granger causality differs across countries within the EEA.

Innovation and Economic Growth in European Economic Area Countries: The Granger Causality Approach

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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 we use in the empirical investigation process. The policy implication of this study is that the economic policies should recognize the differences in innovation and economic growth in order to maintain sustainable development in EEA countries.

Keywords: Innovation, per capita economic growth, Granger causality, EEA countries

1. Introduction

Innovation[1] is a key to economic growth[2], particularly since the seminal work of Schumpeter (1932), and critically important in contemporary economies (Coad et al., 2016; Hausman and Johnston, 2014). It distresses the economy in multiple aspects[3], predominantly on economic growth[4] (Agenor and Neanidis, 2015; Fan, 2011; Grossman, 2009; Grossman and Helpman, 1994; Hudson and Minea, 2013; OECD, 2007; Rogers, 1995), global competitiveness (Galindo and Mendez, 2014; Huang, 2011; Petrakis et al., 2015); financial systems (Aghion and Howitt, 2009; Corrado et al., 2013; de Serres et al., 2006; Hanley et al., 2011; Hsu et al., 2014; Laeven et al., 2015; OECD, 2005b), quality of life (Tellis et al., 2008), infrastructural development (Roig-Tierno et al., 2015; Sohag et al., 2015), employment (Dachs and 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 (see, for instance, Agenor and Neanidis, 2015; Andergassen et al., 2009; Audretsch and Feldman, 1996; Bayoumi et al., 1999; Bottazzi and Peri, 2003; Cameron, 1998; Coe and Helpman, 1995;

[1] Innovation is a concept that has been defined and characterized in many ways by researchers, both as a process and as an outcome (see, for instance, Garcia and Calantone, 2002; Kim and Lee, 2015; OECD, 2005a; Raymond and St-Pierre, 2010).

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

[3] Innovation has its own externalities (Bae and 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.

[5] The measurement of innovation varies from study to study (see, for instance, Griliches, 1990, 1992; Hasan and Tucci, 2010; Hsu et al., 2015; Raymond and St-Pierre, 2010). The common measurements of innovation are patenting activities such as number of patents by residents and number of patents by non-residents. We elaborate these measures of innovation in Section 2.

Francis et al., 2007; Goel and Ram, 1994; Grliches and Mairesse, 1986; Hasan and Tucci, 2010; Kirchhoff et al., 2007; Mansfield, 1980; Maurseth and Verspagen, 2002; Santacreu, 2015; Stokey, 1995). However, these studies only 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 remaining paper is outlined as follows. Section 2 outlines the status of innovation in the EEA countries. Section 3 reflects the proposed hypotheses, variables, data and model. Section 4 presents the empirical results and discussion. Finally, we summarize and conclude in Section 5.

2. An Outline of Innovation in European Economic Area

As cited above, innovation is widely regarded as an important driver of economic growth (Agenor and Neanidis, 2015; Aghion and Howitt, 2009; Aghion et al., 2013; Fan, 2011). There are two ways we can address the innovation issue. First, the disparities issues in innovation activities between countries and second, 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 usage of innovation and then examine its disparity across the European Economic Area countries. In general, innovation can be represented in multiple ways (see, for

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

instance, Pradhan et al., 2016). Nevertheless, we use three types of innovation[7] in this paper. These include number of patents (residents) per thousand of population, number of patents (non-residents) per thousand of population, and total number of patents (both residents and non-residents combined) per thousand of population. A detailed description of these three innovation indicators are available in Table 1.

<<Insert Table 1 here>>

This section highlights the innovation trends in EEA countries. Table reports 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 (PAR, PAN and PAT) in EEA countries are observed on four different time periods from 1989 to 2014[8] (see, Tables 2.1 & 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 are 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, Czech Republic, Greece, and Portugal. This is true for all the four time periods.

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

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

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.

<<Insert Table 2.1 here>>

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 stronger than PAR.

Second, PAR is comparatively high 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.

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.

<<Insert Table 2.2 here>>

3. 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 European Economic Area (EEA) countries over the period 1989 to 2014. We also use cointegration test to recognize whether innovation and per capita economic growth are cointegrated; that is, whether there is a long-run equilibrium relationship between these two variables.

Figure 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.

<<Insert Figure 1 here>>

The freshness of this study is twofold: a) we use a large sample of countries, from European Union, over a recent span of time; and b) we deploy sophisticated econometrics tools– and certain empirical approaches not used in the literature until now– to answer questions concerning the nature of Granger causal relationships[9] between innovation and economic growth, both in the short-run and long-run.

For testing 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 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]

<<Insert Table 3 here>>

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 paper is whether innovation actually causes per capita economic growth or it is

[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.

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 notice the long-run and short-run causal relationship between innovation and per capita economic growth.

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

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

i = 1, 2,... N represents an individual country in the EEA panel;

t = 1, 2, ...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).

Of course, other variations of equation (1) are also entertained to change the dependent variable from per capita economic growth to innovation indicators. When we do individual country analysis, the subscript 'i' can be removed from equation (1). The parameter $\delta_{1Per\ Capita\ Economic\ Growth}$ signifies long-run elasticity estimates of per capita economic growth with respect to

[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.

innovation (PAR/ PAN/ PAT/ RRD). The task is to estimate the parameters in equation (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 at 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.

The following VAR models are used for detecting 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, ..., p***

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

H_0: $\delta_{21k=0}$; and $\eta_{21k} = 0$ ***for k = 1, 2, ..., p***

[14] The VAR model follows the estimation process of Holtz- Eakin et al. (1988).

H_A: $\delta_{21k\,\#0}$; and η_{21k} # 0 ***for k = 1, 2, ..., 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

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

The testable hypotheses are as follows:

H_0: $\delta_{12ik\,=\,0}$; and η_{11ik} = 0 ***for k = 1, 2, ..., p***

H_A: $\delta_{12ik\,\#\,0}$; and η_{11ik} # 0 ***for k = 1, 2, ..., p***

H_0: $\delta_{21ik\,=\,0}$; and η_{21ik} = 0 ***for k = 1, 2, ..., p***

H_A: $\delta_{21ik\,\#0}$; and η_{22ik} # 0 ***for k = 1, 2, ..., p***

where,

i = 1, 2, …., N represents a country in the panel;

t = 1, 2, …., T represents an 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, for knowing 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 and Fuller, 1981) is used for individual country analysis, while ADF - Fisher Chi-square panel unit root test (ADFFC: Maddala and Wu, 1999) is used for the panel setting. In contrast, Johansen (Johansen, 1988) cointegration test 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 due to space constraints and can be incorporated, if required.

4. 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

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

[16] INN is a representative for three innovation indicators such as PAR, PAN, and PAT. A discussion of these variables is available 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).

begins with the stationarity issue. Using unit root (ADF[19] test at each of the individual country and ADFFC[20] 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[21]) 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).

<<Insert Table 4 here>>

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 5-6. 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[22], while it is nonexistent in other countries[23]. In sum, the cointegration between innovation and per capita

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[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 and Granger, 1987; Engle and Yoo, 1987; Granger, 1986).

[19] ADF stands for Augmented Dickey Fuller test (Dickey and Fuller, 1981).

[20] ADFFC stands for ADF - Fisher Chi-square panel unit root test (Maddala and Wu, 1999)

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

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

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

economic growth varies from case to case (for PAR, PAN, PAT, and RRD) and country to country (see, in Table 5 and Table C.1, Appendix C).

<<Insert Table 5 here>>

The presence of cointegration implies that there is a long-run 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 the two variables. The summary of these cointegration test results are reported in Table 6.

<<Insert Table 6 here>>

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 these 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. Using Granger causality test, the estimated results are reported in Tables 7 and 8. 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 in few cases[24], while absence

[24] 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.

in rest of the cases[25]. On the contrary, we have diverging experience in the context of short-run Granger causality between innovation and per capita economic growth. The results of this section are presented below.

<<Insert Table 7 here>>

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).

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

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, 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 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 (see Table C.1).

<<Insert Table 8.1 here>>

<<Insert Table 8.2 here>>

As is evident by these individual country results[26], the nature of the causal relationship between innovation and per capita economic growth are more or less country specific and innovation indicator(s) [27] 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 (neutrality) relationship.

5. Conclusion and Policy Implications

The performance of innovation should not be unnoticed because it plays an imperative role in stimulating economic growth (Hasan and 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 the 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 capita economic growth and innovation) that is a highlight of our study and guides future research on this topic.

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[26] It can be noted that the used sample size might give some caution for the generalizability of our findings. However, the sample size is a good representative of a few countries and the panel. Additionally, we have done couple of robustness checks for this analysis. These include: 1) we have used the normalized data of both innovation and per capita economic growth; 2) we have 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) we have deployed additional cointegration tests (Engle and Granger [1987] at individual country and Pedroni [1999] test at the panel level); and 4) we have tested the VAR/ VECM model by changing the order of lag. Our results are more or less consistent with these robustness checks.

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

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 at the panel setting. On some occasions, per capita economic growth leads to innovation, lending support to demand-following hypothesis of innovation-growth nexus. On some other occasions, 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. It is the situation where both are self-reinforcing and often support to 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 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 for some occasions, 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 government should play a more positive role in order to foster innovation and integrate it with per capita economic growth.

No doubt, in the recent era, many countries including EEA have recognized the importance of innovation for high economic growth and accordingly, they have increased their efforts to have more innovation in their countries. But what is needed is that government of the respective countries should pay high attention to bring in the steady environment in order to promote the link between innovation and per capita economic growth.

Appendix A: Necessity of Linking Innovation and Economic Growth

Since at least from the time of Schumpeter (1932), the process of industrial innovation seems to be an important factor in economic change. He 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 attracted by many empirical researches 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 and 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 (see, for instance, Trajtenberg, 1990). Innovation is considered as one of the key drivers of an economy (Andergassen et al. 2009; Bae and Yoo 2015; Mansfield 1972; Nadiri 1993; Romer 1986; Santacreu 2015; Solow 1956). 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 (see Pradhan et al., 2017).

It is not just that differences in innovation capacity and potential become thus from an endogenous growth perspective (Grossman and Helpman, 1991; Ulku, 2007), one of the basic explanations for persistent differences in wealth and economic performance. By bringing innovation to the fore, 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 localized R&D investment at the heart of technological progress and, eventually, economic growth.

For linking the relationship between innovation activities and economic growth, some understandings draw upon the basic theory of endogenous technical change developed by Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992). The typical version of this theory contains innovation activities which allow a specific entrepreneur to produce one of the many intermediate products at a cost temporarily lower than that of rivals. The extent of innovative activities undertake 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. This 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 for building its future growth and prosperity and safeguarding its social model through innovation. The European Union carved its ambition to become the most competitive knowledge based economic union in the world into its 2002 Lisbon Strategy. An ambitious target of devoting three per cent 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 (Veugelers and Cincera, 2010; Cincera and Veugelers, 2013).

Between 1980 and 2007 in European countries, the significant episodes of economic slowdown occurred more than twice as frequently as the significant episodes of growth accelerations. Economic growth in the EU since the onset of the global financial crisis in 2007 has been disappointing (Lisbon Council E-Book).

Research and innovation is one of the core objectives of the *Europe 2020 Strategy for Smart*, sustainable and inclusive growth (Ciocanel, and 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 and 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 granting 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 (see, for instance, Veugelers, 2008).

Appendix C: Granger Causality between Economic Growth and Researchers in Research and Development Activities

Table C.1: Results of Unit Root Test, Cointegration Test and Granger Causality Test between RRD and GDP

Countries	Unit Root (RRD)	Cointegration		Granger Causality	
	LD/ FD	(r =0/ r=1	r ≤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 ≤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.

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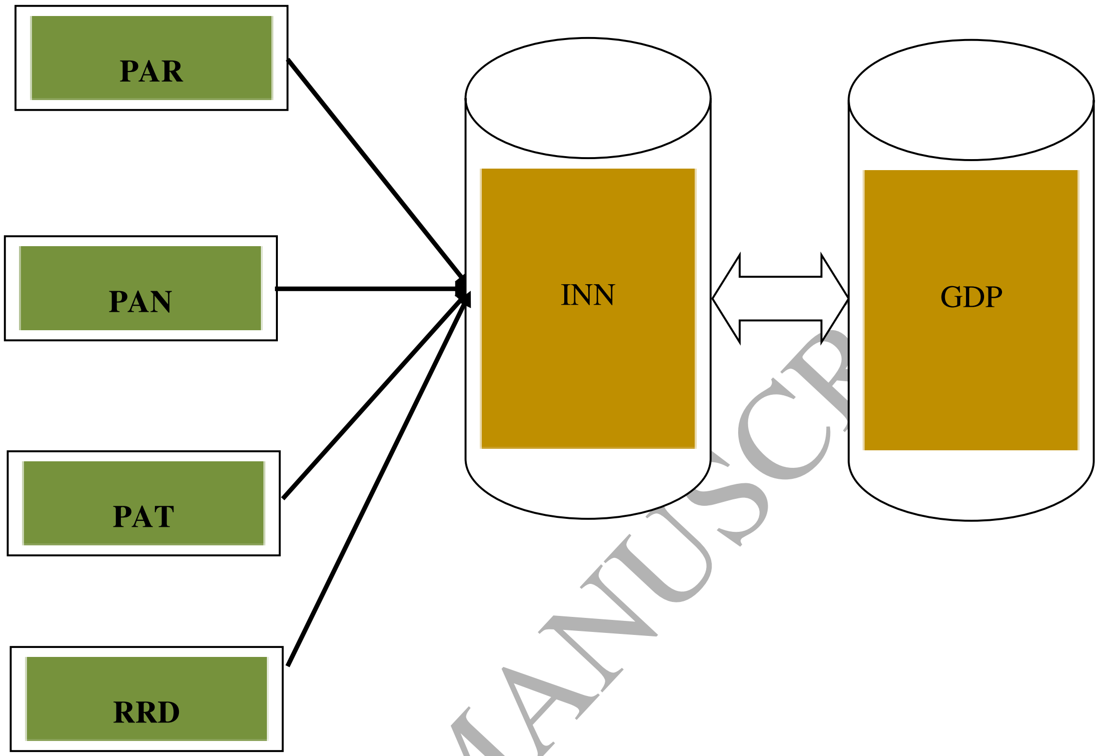

Note 1*: GDP* is per capita economic growth; and *INN* is innovation and used as a proxy for PAR, PAN, PAT, and RRD.

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 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 defined in the *World Development Indicators of World Bank.*

Table 2.1. The Trends of Innovation (in numbers) in European Economic Area Countries

Countries	PAR				PAN				PAT			
	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	12880	14048	14565	13661	3710	3064	1929	3102	16590	17112	16494	16763
Germany	39390	48297	47517	43835	8902	11441	13348	10680	48292	59738	60865	54515
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	10125	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	19324	19191	15613	18396	9235	9939	7087	8917	28559	29130	22700	27313
EEA#	102516	112440	109808	106998	43416	40464	26918	38408	145932	152904	136727	145406

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. The Trends of Innovation (per thousands of population) in European Economic Area Countries

Countries	PAR				PAN				PAT			
	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.

Table 3. Descriptive Statistics and Correlations on the Variables

	Variables				Correlations 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 ***v***alue represent 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.

Table 4. Results of Unit Root Test

Countries	PAR	PAN	PAT	GDP
	Variables			
	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.

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Table 5. Results of Johansen- Juselius Cointegration Test

	Cointegration with GDP					
	λ- max test (r =0/ r=1 r ≤1/ r=2)			λ-Trace test (r =0/ r=1 r ≤1/ r=2)		
Countries	**PAR**	**PAN**	**PAT**	**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 ≤1/ 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 represents 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.

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.

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					
Romania	Romania	Romania			Portugal
	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.