Does Innovation Promote Economic Growth? The Cointegration and Granger Causality Approach in European Countries

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Track B: Regional Innovation: Theory, Methods, Practice

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Abstract

The paper examines the long-run relationship between innovation and per capita economic growth in the 19 European countries over the period 1989-2014. This study uses six different indicators of innovation, such as patents-residents, patents-nonresidents, research and development expenditure, researchers in research and development activities, high-technology exports, and scientific and technical journal articles, to examine this long-run relationships with per capita economic growth. Using cointegration technique, the study finds the evidence of long-run relationship between innovation and per capita economic growth in most of the cases, typically with reference to the use of a particular innovation indicator(s). Using Granger causality test, the study finds the presence of both unidirectional and bidirectional causality between innovation and per capita economic growth. However, these results vary from country to country within the European countries, 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 the innovation and per capita economic growth in order to maintain sustainable development in these selected European countries.

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

JEL Classification: O43, O16, E44

1. Introduction

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

In the past couple of years, both researchers and policy makers have increasingly paid attention to the link between innovation, entrepreneurship and regional outcomes (see, for instance, Galindo and Mendez, 2014, 2013; Grossman, 2009; Howells, 2005; Malerba and Brusoni, 2007; Tsvetkova, 2015; Wong et al., 2005). However in this paper, we specifically[1] look into the linkage between innovation[2] and economic growth in the selected European countries. Innovation is considered as one of the key drivers of the economy (see, for instance, Andergassen et al., 2009; Bae and Yoo, 2015; Mansfield, 1972; Nadiri, 1993; Romer, 1986;

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

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

Solow, 1956), particularly since the seminal work of Schumpeter[3] (1911). It affects the economy in multiple channels, such as economic growth, global competitiveness, financial systems, quality of life, infrastructure development, employment, trade openness, and hence, spawns high economic growth (see, for instance, Agenor and Neanidis, 2015; Aghion and Howitt, 2009; Corrado et al., 2013; Dachs and Peters, 2014; de Serres et al., 2006; Dosi, 1988; Fagerberg, 1994; Fan, 2011; Galindo and Mendez, 2014; Grossman, 2009; Grossman and Helpman, 1994; Hanley et al., 2011; Hsu et al., 2015; Hudson and Minea, 2013; Huang, 2011; Kirchhoff, 1994; Laeven et al., 2015; Mandel, 2009; Navas, 2015; OECD, 2005b; OECD, 2007; Petrakis et al., 2015; Rogers, 1995; Roig-Tierno et al., 2015; Sohag et al., 2015; Tellis et al., 2008; Wennekers, 1999). All these above studies mostly focus the impact of innovation towards the economic growth, indicating the supply driven approach of innovation-growth nexus. But in reality, it is economic growth that can also increase the level of innovation in the development process. That means there is feasibility of bidirectional causality between innovation and economic growth (see, for instance, Pradhan et al., 2016). Hence, the main objective of this paper is to examine the bidirectional linkage between innovation and economic growth. In sum, we like to assess the importance of innovation-economic growth linkage, by investigating whether the level of innovation has contributed to economic growth, or whether the extension of the innovation is simply a consequence of rapid economic growth.

The residual of the paper is sketched as follows. Section 2 summaries the status of innovation in the European countries. Section 3 imitates the proposed hypothesis, variables, data and model.

[3] When Schumpeter wrote bout innovation, he clearly intended to emphasis not only the "destruction" aspect of creative destruction, but the "creative" part as well (see, for instance, Freeman and Soete, 1997; Hasan and Tucci, 2010).

Section 4 gifts the empirical results and discussion. Finally, we summarize and conclude in Section 5.

2. An Outline of Innovation in the European Countries

As cited above, innovation and economic growth cause each other in the development process (Agenor and Neanidis, 2015; Aghion et al., 2010; Fan, 2011). There are two ways we can address the innovation-growth issue. First, the regional disparities of innovation activities and economic growth in the European countries and second, the causal link between innovation and economic growth in these countries. This paper deals with both issues. However, in this section, we address the disparity issue. Overall, innovation can be represented in multiple ways (see, for instance, Pradhan et al., 2016). Nonetheless, we use six different types of innovation[4] in this paper. These include number of patents-residents (PAR), measured per thousand of population; number of patents-non-residents (PAN), measured per thousand of population; research and development expenditure (RDE), measured as a percentage of real gross domestic product; researchers in research and development activities (RRD), measured per thousand population; high-technology exports (HTE), measured as a percentage of real domestic product; and scientific and technical journal articles (STJ), measured per thousand population. The detailed descriptions of these six innovation indicators are available in Table 1.

<<Insert Table 1 here>>

Tables 2.1 and 2.2 provides the general status of innovation indicators in the European countries, both individually and as a group. The status of innovation (PAR, PAN, RDE, RRD, HTE, and STJ) in the European countries are noticed here at four different time periods from

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

1989 to 2014[5] (see, Tables 2.1 & 2.2). These four periods are- P1: 1989- 2000, P2: 2001-2007, P3: 2008-2014, and P4: 1989-2014. The main outlines of this innovation status are as follows.

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

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

Third, the volume of patents- nonresidents are considerably high in Germany, United Kingdom, France, and Norway, while it is relatively low in Belgium, Greece, Portugal, and Romania.

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

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

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

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[5] The choice of these time periods as per the data availability only.

Seventh, the volume of scientific and technical journal articles are relatively high in the countries like Sweden, Finland, Denmark, the United Kingdom, and the Netherlands, while it is considerable low in Romania, Poland, Portugal, and Hungary.

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

<<Insert Table 2.1 here>>

<<Insert Table 2.2 here>>

3. Proposed Hypotheses, Variables, Data Structure and Model

In this section, we empirically test the causality between innovation and per capita economic growth. In specific, the causality between innovation and per capita economic growth can be addressed in four different ways: *supply-leading hypothesis* (SLH) of innovation-growth nexus, where innovation Granger causes per capita economic growth only; *demand-following hypothesis* (DFH) of innovation-growth nexus, where it is the per capita economic growth Granger causes innovation only; *feedback hypothesis* (FBH) of innovation-growth nexus, where both innovation and per capita economic growth Granger cause each other; and *neutrality hypothesis* (NEH) of innovation-growth nexus, where innovation and per capita economic growth independent to each other.

Figure 1 depicts the possible patterns of causal relations between innovation and economic growth. We intend to test the following two hypotheses[6]:

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

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

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

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

<<Insert Figure 1 here>>

The brightness of this study has two folds: a) we use a large sample of countries, from European Union, over a recent span of time; and b) we use the sophisticated econometrics tool– and certainly empirical approaches until now are not taken in these literatures – to answer questions concerning the nature of the Granger causal relationships between innovation and per capita economic growth, both in the short-run and long-run.

The attraction of innovation as a determinant of economic growth (and vice versa) in empirical research is its straightforward measurement. Researchers can use either the input measures such as research and development expenditures (Goel and Ram, 1994; Griliches, 1992; Griliches and Mairesse, 1986; Mansfield, 1972) or innovation outputs such as patents (Audretsch and Feldman, 1996; Bayoumi et al., 1999; Coe and Helpman, 1995; Griliches, 1990; Kim and Lee, 2015; Maurseth and Verspagen, 2002; Pradhan et al., 2016; Stokey, 1995; Wong et al.,

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

2005). But in this study, we deploy both types of innovation indicators (input and output) to investigate the linkage between innovation and economic growth.

On the empirical front, we use two variables: per capita economic growth (variable: GDP[7]) and innovation (variable: INN[8]). Table 3 presents the descriptive statistics of these innovation variables, particularly with reference to PAR, PAN, RDE, RRD, HTE, and STJ.

<<Insert Table 3 here>>

We take the sample of 19 European countries[9] to investigate the validity of both $H_{1A, B}$ and $H_{2A, B}$. The empirical investigation follows annual data over the period 1989 to 2014 and was obtained from the *World Development Indicators* of the World Bank. The study deploys cointegration and Granger causality (Granger, 1988; 1986) to validate the above two hypotheses (H_{1A}^0 *and* H_{1B}^0). We have six different cases to validate these two hypotheses, particularly with reference to six different indicators of innovation. Case 1 deals with GDP and PAR, Case 2 deals with GDP and PAN, Case 3 deals with GDP and RDE, Case 4 deals with GDP and RRD, Case 5 deals with GDP and THE, and Case 6 deals with GDP and STJ.

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

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[7] GDP represents the level of economic growth.

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

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

Model 1: For Individual country analysis

$$\Delta GDP_t = \alpha_1 + \sum_{k=1}^{p} \beta_{1k} \Delta GDP_{t-k} + \sum_{k=1}^{q} \lambda_{1k} \Delta INN_{t-k} + \delta_1 ECT_{t-1} + \varepsilon_{1t} \tag{1}$$

The testable hypotheses are:

H_0: $\lambda_{1k} = 0$; and $\delta_1 = 0$ for k = 1, 2, ..., p

H_A: $\lambda_{1k} \# 0$; and $\delta_1 \# 0$ for k = 1, 2, ..., p

$$\Delta INN_t = \alpha_2 + \sum_{k=1}^{p} \beta_{2k} \Delta INN_{t-k} + \sum_{k=1}^{q} \lambda_{2k} \Delta GDP_{t-k} + \delta_2 ECT_{t-1} + \varepsilon_{2t} \tag{2}$$

The testable hypotheses are:

H_0: $\lambda_{2k} = 0$; and $\delta_2 = 0$ for k = 1, 2, ..., p

H_A: $\lambda_{2k} \# 0$; and $\delta_2 \# 0$ for k = 1, 2, ..., p

where,

ECT[10] is error correction term, which is derived from the long-run cointegration equation;

p and q are the lag lengths for the estimation;

Δ is the first difference operator; and

ε_{1t} and ε_{2t} are the independently and normally distributed random error with a zero mean and a finite heterogeneous variance.

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

Model 2: For panel data analysis

$$\Delta GDP_{it} = \alpha_{3j} + \sum_{k=1}^{p} \beta_{3ik} \Delta GDP_{it-k} + \sum_{k=1}^{q} \lambda_{3ik} \Delta INN_{it-k} + \delta_{3i} ECT_{it-1} + \varepsilon_{3it} \tag{3}$$

The testable hypotheses are:

H_0: $\lambda_{3ik = 0}$; and δ_{3i} = 0 for k = 1, 2, ..., p

H_A: $\lambda_{3ik \# 0}$; and δ_{3i} # 0 for k = 1, 2, ..., p

$$\Delta INN_{it} = \alpha_{4j} + \sum_{k=1}^{p} \beta_{4ik} \Delta GDP_{it-k} + \sum_{k=1}^{q} \lambda_{4ik} \Delta INN_{it-k} + \delta_{4i} ECT_{it-1} + \varepsilon_{4it} \tag{4}$$

The testable hypotheses are:

H_0: $\lambda_{4ik = 0}$; and δ_{4i} = 0 for k = 1, 2, ..., p

H_A: $\lambda_{4ik \# 0}$; and δ_{4i} # 0 for k = 1, 2, ..., p

where,

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

t = 1, 2, …., T represents the year in the panel.

This study uses HQIC[11] statistics to select the optimum lag length.

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

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

and the panel setting, for knowing the order of integration and the presence of cointegrating relationship between innovation and per capita economic growth.

The Augmented Dickey Fuller (ADF) unit root test (Dickey and Fuller, 1981) is used for individual country analysis, while the ADF - Fisher Chi-square panel unit root test (Maddala and Wu, 1999) is used for the panel settings. In contrast, Johansen cointegration test (Johansen, 1988) is deployed for individual country analysis, while the Fisher/ Maddala cointegration test (Maddala and Wu, 1999; Fisher, 1932) is deployed at the panel setting. The details of these two unit root tests (unit root and cointegration) are not available here and can be incorporated, if there is any necessity.

4. Empirical Results and Discussion

The discussion begins with order of integration and cointegration between innovation[12] and per capita economic growth. Using unit root (simple ADF test at each of the individual country and panel ADF[13] at the panel setting), we reject the null hypothesis of unit root at the first difference but not at the level data. Table 4 presents these unit root test results, both for individual country and at the European panel. The results indicate that innovation (INN: PAR, PAN, RDE, RRD, HTE, and STJ) and per capita economic growth (GDP) are non-stationary at the level data but are stationary at the first difference. This is true for all the 19 European countries, both at the individual country and at the group level (panel setting). The findings suggests that both innovation and per capita economic growth are integrated of order one [i.e. I

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

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

(1)], which unbolts the possibility of cointegration between the two (innovation and per capita economic growth).

<<Insert Table 4 here>>

In the succeeding step, we deploy the Johansen Maximum Likelihood cointegration test (by λ_{Tra} and λ_{Max} test) at the individual country and Fisher cointegration test at the panel setting for checking the simulation of cointegration between innovation and per capita economic growth. The results of both the test statistics are reported in Tables 5.1-5.3. Tables 5.1 and 5.2 report λ_{Tra} and λ_{Max} test statistics respectively, while Tables 5.3 reports the summary of cointegration test. These results indicate that innovation and per capita economic growth are cointegrated in some European countries[14], while it is not-cointegrated in other European countries[15]. All in all, the cointegration between innovation and per capita economic growth varies from case to case (for PAR, APN, RDE, RRD, HTE, and STJ) and country to country (see, Table 5.3).

<<Insert Table 5.1 here>>

<<Insert Table 5.2 here>>

The incidence of cointegration infers that there is a long-run equilibrium relationships between innovation and per capita economic growth (Engle and Granger, 1987). On the contrary, the absence of cointegration indicates that there is no long-run relationship between these two variables. The summary of these cointegration test results are reported in Table 5.3.

<<Insert Table 5.3 here>>

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

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

In the next section, we detect the Granger causality by deploying vector error correction model (VECM) for the presence of cointegration between innovation and per capita economic growth, and simple vector autoregressive (VAR) model for the absence of cointegration between these two. Having established the animation 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 6.1-6.5. Tables 6.1 and 6.2 report the presence of both short-run and long-run equilibrium relationships between innovation and per capita economic growth, while Tables 6.3-6.5 report the summary of short-run Granger causal nexus between these two sets of variables (GDP vs. PAR; GDP vs. PAN; GDP vs. RDE; GDP vs. RRD; GDP vs. HTE, and GDP vs. STJ). The analysis is based on the individual indicators of innovation and per capita economic growth. Coming to long-run equilibrium relationships[16], we find the presence in few cases[17], while absence in rest of the cases[18]. 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 6.1 here>>

<<Insert Table 6.2 here>>

<<Insert Table 6.3 here>>

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[16] Detected through the significance of error correction term (ECT) [see equations 1-4].

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

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

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

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

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

For the countries like Austria, Belgium, Czech Republic, France, the Netherlands, Romania, Spain, and Sweden, there is a unidirectional causality from innovation to per capita economic growth (PAN => GDP), whereas for Finland, Germany, Greece, and Norway, we find the unidirectional causality from per capita economic growth to innovation (GDP => PAN). In addition, for the countries like Denmark, Hungary, Ireland, Portugal, the United Kingdom, and the European panel, we find the bidirectional causality between innovation and per capita economic growth (PAN <=> GDP), while in the context of Italy, and Poland, we find per capita economic growth does not Granger cause innovation (GDP <#> PAN).

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

For the countries like Belgium, Denmark, Finland, France, Germany, Italy, Norway, Poland, Portugal, Spain, and the United Kingdom, we detect the unidirectional causality from innovation to per capita economic growth (RDE => GDP), whereas for the countries like Austria, Czech

Republic, Ireland, the Netherland, Romania, and Sweden, we find the unidirectional causality from per capita economic growth Granger causes innovation (GDP => RDE). Additionally, for European panel, we find the existence of bidirectional causality between innovation and per capita economic growth (RDE <=> GDP), while in the context of Greece, per capita economic growth does not Granger cause innovation (RDE <#> GDP).

Case 4: Between innovation (RRD) and per capita economic growth (GDP)

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 European panel, there is bidirectional causality between innovation and per capita economic growth (RRD <=> GDP), while in the context of Greece and Sweden, per capita economic growth does not Granger cause innovation (RRD <#> GDP).

Case 5: Between innovation (HTE) and per capita economic growth

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

Case 6: Between innovation (STJ) and per capita economic growth

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

<<Insert Table 6.4 here>>

<<Insert Table 6.5 here>>

As it is evident by these individual country results[19], the nature of the causal relationship between innovation and per capita economic growth are more or less country specific and the

[19] It may be noted that the used sample size might give some attention for the generalizability of our findings. However, the sample size is well representative for few countries and at the panel level. Moreover, we have conducted couple of robustness checks to this analysis. These include: 1) we have deployed the normalized data of both innovation indicators and per capita economic growth; 2) we have added additional unit root tests (KPSS [Kwiatkowski, Phillips, Schmidt, and Shin, 1992] unit root test at the individual country and LLC [Levine, Lin, and Chu, 2002] 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

specification of innovation indicator (s) [20]. In some cases, innovation Granger causes per capita economic growth, while in the latter case, it is the per capita economic growth that actually Granger causes the 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 the independent (neutrality) relationship.

5. Conclusion and Policy Implications

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

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

4) we have tested the VAR/ VECM model by changing lag structure. Our results are more or less consistent with these robustness checks.

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

and per capita economic growth are mutually interdependent. That is the situation where both are self-reinforcing and subject to the support of feedback hypothesis of innovation-growth nexus. Additionally, there are also suitcases, where innovation and per capita economic growth are independent to each other. That is the situation where both are neutral and subject to the support of 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 the innovation. Given the possibility of reverse causality or bi-directional causality for some junctures, policies that increase the per capita economic growth (such as actions to increase investment) would be desirable to bring more innovation in the economy. Consequently, what is redolent is that government should play a more positive role in order to foster the innovation and then integrates it with per capita economic growth.

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

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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:** expressed in numbers and used per thousand population.
PAN	**Patents filed by non-residents:** expressed in numbers and used per thousand population.
RDE	**Research and development expenditure**: used as a percentage of real gross domestic product
RRD	**Researchers in research and development activities**: expressed in numbers and used per thousand population.
HTE	**High-technology exports:** used as a percentage of real gross domestic product.
STJ	**Scientific and technical journal articles**: expressed in numbers and used per thousand population.

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

Table 2.1. The Trends of Innovation (per thousands of population) in European Countries

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

Note 1: PAR is number of patents residents; PAN is number of patents non-residents; and RDE is research and development expenditure.

Note 2: P1 is 1989-2000; P2 is 2001-2007; P3 is 2008-2014; and p4 is 1989-2014.

#: The figures are average of all 19 European countries.

Table 2.2. The Trends of Innovation (per thousands of population) in European Countries

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

Note 1: RRD is researchers in research and development activities; HTE is the high-technology exports; and STJ is the scientific and technical journal articles.

Note 2: P1 is 1989-2000; P2 is 2001-2007; P3 is 2008-2014; and p4 is 1989-2014.

#: The figures are average of all 19 European countries.

Table 3. Descriptive Statistics of the Variables

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

Note 1: PAR is number of patents residents; PAN is number of patents non-residents; RDE is research and development expenditure; RRD is the researchers in research and development activities; HTE is the high-technology exports; and STJ is the scientific and technical journal articles; and GDP is per capita economic growth.

Note 2: Open ***v***alues represent the mean of the variables, while [ ] 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.

#: The reported statistics are calculated at the panel level.

Table 4. Results of Unit Root Test

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

Note 1: PAR is number of patents residents; PAN is number of patents non-residents; RDE is research and development expenditure; RRD is the researchers in research and development activities; HTE is the high-technology exports; and STJ is the scientific and technical journal articles; and GDP is per capita economic growth.

Note 2: Figures in parentheses represent the order of integration.

Note 3*:* ADF is Augmented Dickey Fuller test statistics.

Note 4*:* 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 5**:** * is statistical significance at 1% level; and ** is statistical significance at 5% level.

#: The reported statistics are calculated at the panel level.

Table 5.1 Results of Johansen- Juselius Cointegration Test (Max Test)

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

Note 1: PAR is number of patents residents; PAN is number of patents non-residents; RDE is research and development expenditure; RRD is the researchers in research and development activities; HTE is the high-technology exports; and STJ is the scientific and technical journal articles; and GDP is per capita economic growth.

Note 2*:* r represents number of cointegrating vector.

Note 4: We observe statistical significance at 5% level.

Note 5: For Cointegration, the open values represent the figure for r=0/r=1, while the bracketed value represents the figure for $r \leq 1$/ 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.

Table 5.2 Results of Johansen- Juselius Cointegration Test (Trace Test)

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

Note 1: PAR is number of patents residents; PAN is number of patents non-residents; RDE is research and development expenditure; RRD is the researchers in research and development activities; HTE is the high-technology exports; and STJ is the scientific and technical journal articles; and GDP is per capita economic growth.

Note 2*:* r represents number of cointegrating vector.

Note 4: We observe statistical significance at 5% level.

Note 5: For Cointegration, the open values represent the figure for r=0/r=1, while the bracketed 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.

Table 5.3. Summary of Cointegration Test Results

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

Note 1: *Case 1 is* cointegration between *PAR* and GDP; Case 2 is cointegration between *PAN* and GDP; Case 3: cointegration between *RDE* and GDP; *Case 4:* cointegration between *RRD* and GDP; Case 5: cointegration between *HTE* and GDP; Case 6: cointegration between *STJ* and GDP

Note 2: PAR is number of patents residents; PAN is number of patents non-residents; RDE is research and development expenditure; RRD is the researchers in research and development activities; HTE is the high-technology exports; and STJ is the scientific and technical journal articles; and GDP is per capita economic growth.

Note 3*:* 0 stands for absence of cointegration between innovation (PAR/ PAN/ RDE/ RRD/ HTE/ STJ) and per capita economic growth, 1 stands for presence of one cointegrating vector between innovation (PAR/ PAN/ RDE/ RRD/ THE/ STJ) and per capita economic growth, and 2 stands for presence of two cointegrating vectors between innovation (PAR/ PAN/ RDE/ RRD/ HTE/ STJ) and per capita economic growth.

Note 4: CR is Czech Republic, UK is United Kingdom, and EP is European panel.

Note 5: Parentheses indicate number of cointegrating vector (s).

Note 6: Results are derived on the basis of Tables 5.1 and 5.2 results.

Table 6.1 Results of Test from the Error Correction Model for Long-Run Causality

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

Note 1: GDP is per capita economic growth; PAR is number of patents residents; PAN is number of patents non-residents; and RDE is research and development expenditure.

Note 2: the short-run causality is detected through the 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 value represents GDP as the dependent variable and the second value represents innovation as the dependent variable (PAR/ PAN/ RDE).

Note 4: '*' indicates the statistical significance at 5% level and '**' indicates the statistical significance at 10% level.

Table 6.2 Results of Test from the Error Correction Model for Long-Run Causality

	Granger Causality Test between					
	RRD and GDP		HTE and GDP		STJ and GDP	
Countries	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Austria	3.20**/0.40	NA/NA	0.89/0.63	-3.18**/-0.99	1.64/6.54*	-1.53/-2.13
Belgium	13.6*/1.19	NA/NA	3.40*/0.48	NA/NA	0.32/5.03*	-1.29/-2.85
Czech Republic	5.14*/0.41	NA/NA	1.76/0.01	NA/NA	1.27/0.43	NA/NA
Denmark	0.46/5.28*	NA/NA	0.51/0.19	-1.92/-2.26	0.06/21.1*	-1.96/-4.13*
Finland	0.07/25.3*	NA/NA	18.3/3.73	-3.46**/-0.32	36.8*/0.92	-6.10/-2.12
France	3.12**/2.12	-2.35/-1.13	3.41*/0.09	NA/NA	8.21*/0.44	-0.66/-5.31*
Germany	5.31*/0.18	NA/NA	12.2*/3.07**	-5.94*/-1.82	0.40/4.06*	-2.65/-1.93
Greece	---/---	---/---	1.33/1.85	---/---	8.49*/5.33*	---/---
Hungary	7.12*/0.46	-4.14*/-1.26	1.20/19.6*	-2.25/-4.37*	5.298/0.97	NA/NA
Ireland	0.99/3.62**	NA/NA	18.1*/0.26	NA/NA	2.02/4.19*	NA/NA
Italy	4.43*/0.47	NA/NA	2.10/9.59*	-3.64*/-2.07	0.02/11.4	-0.65/-4.68*
Netherlands	1.34/6.33*	NA/NA	7.60*/1.18	0.22/-2.65	3.51*/5.59*	NA/NA
Norway	0.01/5.86*	NA/NA	0.90/4.97*	-0.16/-3.90*	2.89**/6.04*	NA/NA
Poland	0.75/5.68*	-0.86/-1.90	0.67/3.03**	NA/NA	2.48/3.05**	NA/NA
Portugal	9.83*/1.46	NA/NA	1.33/3.53*	NA/NA	17.9*/2.57	-4.52*/-1.35
Romania	3.84*/3.74*	-7.97*/1.96	0.50/3.66*	-1.26/-3.61**	3.87*/1.85	NA/NA
Spain	0.15/6.46*	-0.62/-3.14	1.04/11.3*	NA/NA	5.58*/2.05	-1.15/-4.73*
Sweden	1.45/0.15	NA/NA	3.26*/0.87	-3.52**/-0.66	8.15*/4.55*	NA/NA
United Kingdom	9.47*/2.25	NA/NA	25.9*/0.82	NA/NA	1.14/9.10*	NA/NA
European Panel	3.03*/2.95*	-6.15*/-1.23	7.95*/4.41*	-6.31*/-1.69	2.13/6.88*	-7.09*/-2.56

Note 1: PAR is number of patents residents; PAN is number of patents non-residents; RDE is research and development expenditure; RRD is the researchers in research and development activities; HTE is the high-technology exports; and STJ is the scientific and technical journal articles; and GDP is per capita economic growth.

Note 2: the short-run causality is detected through the 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 value represents GDP as the dependent variable and the second value represents innovation as the dependent variable (RRD/ HTE/ STJ).

Note 4: '*' indicates the statistical significance at 5% level and '**' indicates the statistical significance at 10% level.

Table 6.3 Summary of Granger Causality Test

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

Note 1: *Case 1 is* cointegration between *PAR* and GDP; Case 2 is cointegration between *PAN* and GDP; Case 3: cointegration between *RDE* and GDP; *Case 4:* cointegration between *RRD* and GDP; Case 5: cointegration between *HTE* and GDP; Case 6: cointegration between *STJ* and GDP

Note 2: PAR is number of patents residents; PAN is number of patents non-residents; RDE is research and development expenditure; RRD is the researchers in research and development activities; HTE is the high-technology exports; and STJ is the scientific and technical journal articles; and GDP is per capita economic growth.

Note 3: SLH indicates the unidirectional causality from innovation to economic growth; DFH indicates the unidirectional causality from economic growth to innovation; FBH indicates the bidirectional causality between innovation and economic growth; and NLH is neutrality hypothesis indicates no causal flow between innovation and economic growth.

Note 4: Results are derived on the basis of Tables 6.2 and 6.3 results.

Table 6.4 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	Denmark	Czech Republic		Ireland
Finland		Finland	Denmark		Netherlands
France	France	France		Finland	Romania
Germany		Germany		Germany	Sweden
Greece		Hungary		Greece	
Italy	Italy	Italy	Hungary		
Netherlands	Netherlands	Norway	Ireland		
		Poland	Norway	Norway	
		Portugal		European Panel	
Portugal		Spain			
Romania	Romania	United Kingdom			
	Spain				
	Sweden				
United Kingdom					
Feedback hypothesis of innovation-growth nexus			**Neutrality hypothesis of innovation-growth nexus**		
Case 1	**Case 2**	**Case 3**	**Case 1**	**Case 2**	**Case 3**
Austria					
	Denmark	Finland			
		Greece			
	Hungary			Italy	
	Ireland	Ireland			
		Netherlands			
Poland					
	Protugal			Poland	
Spain					
Swedeen					
	United Kingdom				
European Panel		European Panel			

Note 1: *Case 1 is* cointegration between *PAR* and GDP; Case 2 is cointegration between *PAN* and GDP; and Case 3: cointegration between *RDE* and GDP.

Note 1: PAR is number of patents residents; PAN is number of patents non-residents; RDE is research and development expenditure; and GDP is per capita economic growth.

Note 3: Results are derived on the basis of Table 6.3 results.

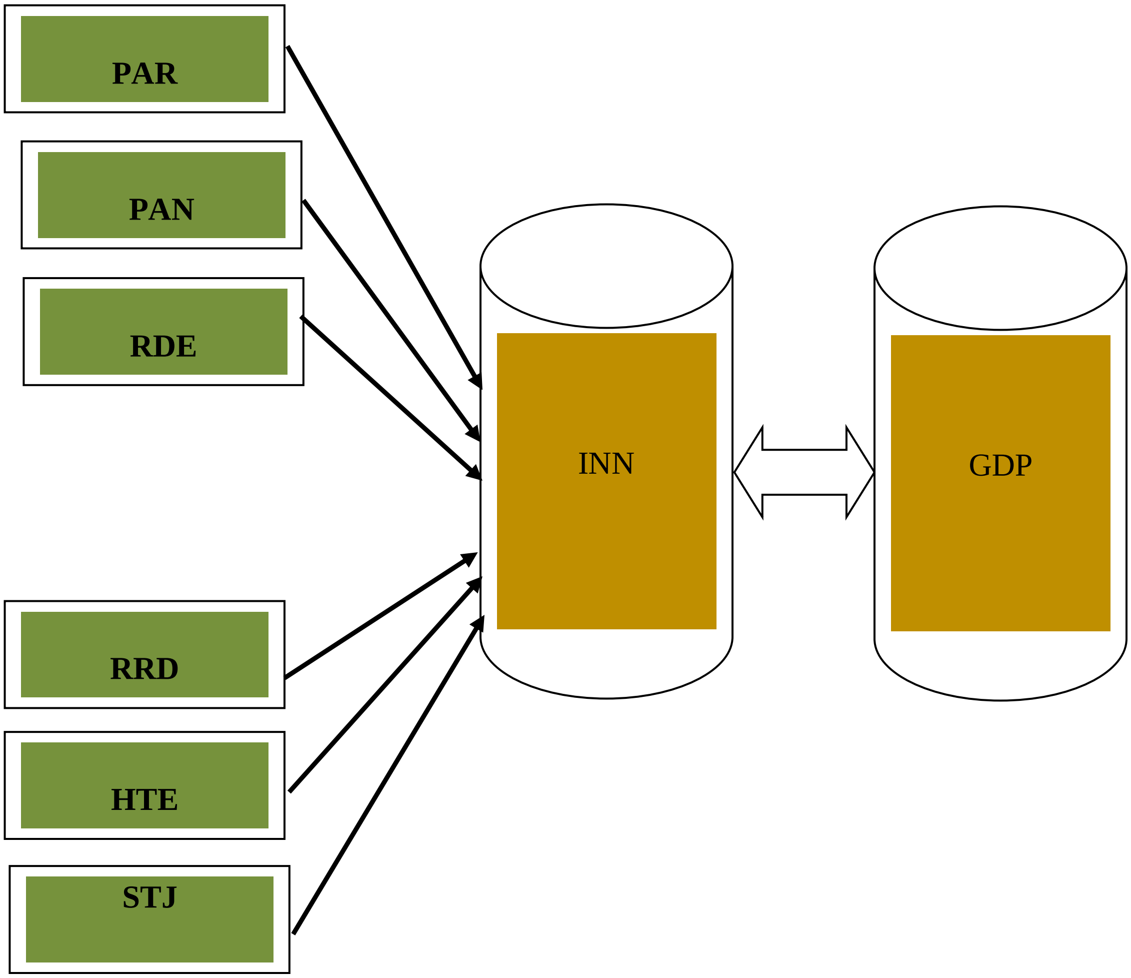
Table 6.5 Summary of Granger Causality Test Results

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

Note 1: *Case 4:* cointegration between *RRD* and GDP; Case 5: cointegration between *HTE* and GDP; and Case 6: cointegration between *STJ* and GDP

Note 2: RRD is researchers in research and development activities; HTE is high-technology exports; STJ is scientific and technical journal articles; and GDP is per capita economic growth.

Note 3: Results are derived on the basis of Table 6.3 results.



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

Note 2: PAR is number of patents residents; PAN is number of patents non-residents; RDE is research and development expenditure; RRD is the researchers in research and development activities; HTE is the high-technology exports; and STJ is the scientific and technical journal articles.

Figure 1: Conceptual Framework of the Causality between Innovation and Per Capita Economic Growth