Endogenous Dynamics Between Innovation, Financial Markets, Venture Capital and Economic Growth: Evidence from Europe

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Highlights for Review

- We consider the links among venture capital investment, innovation, financial development and economic growth.
- A panel Granger causality test is used to examine the possible links.
- We use a panel of 23 European countries from 1989 to 2015.
- Short-run results show complex links depending on different measures of the variables.
- The three variables considered are key drivers of economic growth regardless of measures that are used.

Abstract

Much of the literature on venture capital (VC) investment focuses on the impact of such investment on firm performance. Although some studies consider the link between VC investment, innovation, and economic growth (usually in a pair), the role of financial development in these relationships is often considered only in the periphery, if it is considered at all. The present study uses a panel vector error-correction model to study the Granger causality among VC investment, innovation, per capita economic growth, and financial development. We study 23 European countries over the period of 1989-2015 and consider several different measures of innovation based on indicators such as patenting, trademarks, research and development, and researcher activities. The empirical results indicate that all three variables (VC investment, financial development, and innovation) contribute to long-term economic growth. The results also show strong endogenous relationships among the four variables in the short run based on the types of innovation indicators and venture capital measures used in the empirical model. The short-run and long-run analysis between the variables provides important policy implications for securing sustained economic growth in Europe.

Keywords: Venture capital investment; innovation; financial development; economic growth; Granger causality; European countries

JEL Classification: O43, O16, E44, E31

1. INTRODUCTION

Venture capital is increasingly becoming an important source of capital for firms that might not otherwise have access to traditional sources of financing for innovation. The firms that seek venture capital are typically small, privately-held, relatively young, and in potential high-growth industries. Venture capital firms provide these entrepreneurial firms with capital[1] in exchange for an equity position in the company. In addition to bringing capital to these young firms, venture capital investment also brings other benefits in the form of additional experience, skills, and contacts for the entrepreneurial firm.

It has been shown that venture capital investment plays an important role in innovation[2]. Silicon Valley and other similar innovation technology corridors have been heavily influenced by venture capital through both financing and other support services such as recruiting, legal advice, consulting, etc. (see, for example, Florida and Kenny, 1988b; Florida and Smith, 1990; Castilla, 2003). The inflow of capital into the innovation technology corridors have led to significant increases in patents filed by firms in these localities. For example, from 2007 to 2011, the San Jose-Sunny Valley-Santa Clara metropolitan statistical area (MSA) averaged 9,237 patents granted annually and 5,066 patents per million residents, while over the same time period the San Francisco-Oakland-Fremont MSA averaged 7,003 patents granted annually with 1,638 patents per million residents[3]. To put this in perspective, the average number of patents granted annually for all MSAs in the U.S. was 299, with 296 patents per million residents.

[1] Venture capital funds are financial intermediaries that raise and professionally manage pools of money to invest in young, privately-held companies. The venture capitalist typically serves as a director, advisor, or manager of the company that is receiving venture capital funds (see, *inter alia*, Cochrane, 2005; Cumming and MacIntosh, 2007; Kortum and Lerner, 1998).

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

[3] Rothwell et al. (2013)

The majority of research on venture capital focuses on the impact that venture capital investment have on firm performance[4] or its impact on overall venture capital industry development. However, more recent studies focus on the nexus between venture capital, innovation, and economic growth. Specifically, there is interest in the causal relationship between these variables to better understand the complex dynamics that govern the underlying structure of the economy. For instance, does venture capital investment lead to economic development, or does economic development promote venture capital investment? Research indicates that venture capital is related to economic development (see, *inter alia*, Samila and Sorenson, 2011; Fuss and Schweizer, 2012; Carvell et al., 2013); however, there is no clear consensus on the direction of this relationship.

While there are numerous studies highlighting the relationships between venture capital, innovation, and/or economic development – usually in a pair (see, *inter alia*, Berger and Schaeck, 2011; Florida and Smith, 1990; Florida and Kenney, 1988a,b; Kortum and Lerner, 2000), from an empirical perspective, omitting one of these variables from the analysis could lead to biased results. To be clear, research should examine the determinants of economic growth in the presence of *both* venture capital investment and innovation. Previous studies have shown that higher economic growth requires more innovation. Additionally, venture capital investment has often been seen as a key determinant for both innovation and economic growth. Therefore, it is worthwhile to investigate the nexus among innovation, venture capital investment, and economic growth by considering *all* three simultaneously in an econometric model. Furthermore, we maintain that considering the state of the financial development of a country is necessary to complete the picture. Thus, this study contributes to the literature by examining

[4] See, for example, Berger and Schaeck (2011), Cochrane (2005), Cumming and MacIntosh. (2007), and Gompers (1995).

the causal link between VC investment, innovation, financial development,[5] and economic growth. That is, we study the causal links between any two variables in the presence of the other two.

To study the short-run and long-run causal links between these four variables, we consider a sample of 23 European countries and utilize a vector error-correction model (VECM). The empirical results will provide valuable insights for developing the financial and VC ecosystems to support sustainable economic development models in these countries.

The rest of the paper is arranged as follows. Section 2 presents the literature review. Section 3 explains the empirical model and the data used for the study. Section 4 presents the empirical results and a discussion of these results. Section 5 concludes and provides the policy implications.

2. LITERATURE REVIEW

This section provides an overview of four strands of literature, particularly with reference to the Granger causal relationships among venture capital investment, financial development, innovation, and economic growth.

The first strand of literature considers the link between venture capital investment and economic growth. The causal relationship between these two variables can be addressed in four different ways. Firstly, the *supply-leading hypothe*sis (SLH[a]) of the venture capital-growth nexus states that venture capital investment Granger causes economic growth. The supporters of this hypothesis are Keuschnigg (2004), Samila and Sorenson (2011), and Pradhan et al. (2016a).

[5] While there is substantial literature studying the relationship between economic growth and VC investment, there is a lack of studies on the relationship between financial market development and VC investment. In this study, we examine the inter-relationship between financial development and VC investment and two other variables.

Secondly, the *demand-following hypothesis* (DFH[a]) of the venture capital-growth nexus maintains that economic growth Granger causes venture capital investment. The proponents of this hypothesis are Gompers and Lerner (1998), Fuss and Schweizer (2012), Carvell et al. (2013), and Pradhan et al. (2016a). Thirdly, the *feedback hypothesis* (FBH[a]) of the venture capital-growth nexus contends that there is bidirectional causality between venture capital investment and economic growth in that higher economic growth requires more venture capital investment and more venture capital investment leads to a higher level of economic growth (Pradhan et al., 2016a). The final hypothesis is the *neutrality hypothesis* (NEH[a]), where there is no Granger causality between venture capital investment and economic growth, i.e., economic growth and venture capital investment occur independently (Fuss and Schwiezer, 2012; Pradhan et al., 2016a).[6]

The second strand of the literature studies the relationship between financial development and economic growth. Like the previous case, the Granger causality between the two can be addressed in four different ways. Firstly, the *supply-leading hypothesis* (SLH[b]) of the financial development-growth nexus postulates that financial development Granger causes economic growth. This hypothesis is supported by Calderon and Liu (2003), Chaiechi (2012), Christopoulos and Tsionas (2004), Hsueh et al. (2013), Jalil et al. (2010), and Kar et al. (2011). Secondly, the *demand-following hypothesis* (DFH[b]) of the financial development-growth nexus holds that economic growth Granger causes financial development. The advocates of this hypothesis are Ang and McKibbin (2007), Kar et al. (2011), Levine (1997), Liang and Jian-Zhou (2006), and Odhiambo (2010). Thirdly, the *feedback hypothesis* (FBH[b]) of the financial development-growth nexus states that both financial development and economic growth Granger cause each

[6]Among the previous studies on the venture capital-growth nexus, Pradhan et al. (2016a) is the only study where all four hypotheses (SLH, DFH, FBH, and NEH) are supported. A possible explanation is that they study individual countries, with different results for each country.

other as higher financial development leads to more economic growth, which in turn leads to higher financial development. The followers of this hypothesis include Pradhan et al. (2014), Calderon and Liu (2003), Craigwell et al. (2001), Dritsakis and Adamopoulos (2004), Esso (2010), and Wolde-Rufael (2009). Fourthly, the *neutrality hypothesis* (NEH[b]) of the financial development-growth nexus contends that both financial development and economic growth do not Granger cause each other. This hypothesis is supported by the work of Lucas (1988) and Robinson (1952). Finally, some studies offer mixed evidence.

The third strand of the literature considers the relationship between innovation and economic growth (see, *inter alia*, Romer, 1986; Solow, 1956; Schumpeter 1911, 1932). Like the previous two cases, the causality between innovation and economic growth can be addressed in four different ways. Firstly, the *supply-leading hypothesis* (SLH[c]) of the innovation-growth nexus holds that innovation Granger causes economic growth as innovation increases marginal productivity and output. The proponents of this hypothesis are Agenor and Neanidis (2015), Grossman and Helpman (1991, 1994), Guloglu and Tekin (2012), Kirchhoff et al. (2007), and Pradhan et al. (2016b). Secondly, the *demand-following hypothesis* (DFH[c]) of the innovation-growth nexus states that economic growth Granger causes innovation only. The followers of this hypothesis are Howells (2005), Pradhan et al. (2016b), and Sadraoui et al. (2014). Thirdly, the *feedback hypothesis* (FBH[c]) of the innovation-growth nexus posits that both innovation and per capita economic growth Granger cause each other as higher growth leads to more innovation, which in turn leads to higher economic growth. The followers of this hypothesis include Galindo and Mendez (2014), Hasan and Tucci (2010), Howells (2005), and Pradhan et al. (2016b). Fourthly, the *neutrality hypothesis* (NEH[c]) of the innovation-growth nexus contends that both innovation and economic growth are determined independently of each other. The supporters

of this hypothesis are Pradhan et al. (2016b). Interestingly, some studies offer mixed evidence. For instance, Pradhan et al. (2016a) support the validity of all four hypotheses.[7]

Appendix A, Table A.1, presents a brief synopsis of the three strands of literature discussed above.

In addition to these three strands, there are also studies that examine bilateral links between venture capital investment and innovation, between venture capital and financial development, or between financial development and innovation. Once again, four hypotheses (SLH, DFH, FBH and NEH) may be formed with respect to each of these individual relationships. Barry and Mihov (2015) and Pradhan et al. (2016a, 2017) are examples of the few studies that present evidence in favour of some of these hypotheses. It suffices to say that such evidence is rather sparse.

3. METHODOLOGY

The present paper contributes to the literature by examining the dynamics between VC investment, innovation, and economic growth in the presence of the state of development of the financial sector. This relationship is examined using a panel Granger-causality test for 23 European countries. In this section, we develop our hypotheses and describe the data, the variables, and the empirical methodology.

3.1 Development of Hypotheses

In this paper, we propose an integrated framework that examines the relationship between VC investment, innovation, financial development, and economic growth. The conceptual model to capture the possible relationships between these variables is

[7] A possible explanation for this finding is the authors' use of different indicators for innovation.

provided in Figure 1. Based on the conceptual model, several hypotheses are tested and discussed below.

***First, the link between venture capital investment and economic growth*:**

Venture capital (VC) is seen as an important enabler for firms that are highly innovative and technology-intensive to acquire much needed capital for expanding their businesses. VC can be provided at the early or later stages of business ventures and their contribution to economic growth are via several channels, discussed below.

In the early stages, start-up businesses (known as start-ups) face numerous challenges, including acquisition of appropriate technology, research and development (R&D), and expertise to develop their core intellectual property or technology (Elango et al., 1995). Many of these start-up businesses also experience difficulties in gaining access to markets (Elango et al., 1995). Due to these challenges, many of the early start-ups require early stage funding for R&D and acquisition of other resources that will help develop their core technology and value proposition. Early stage VC funding also comes with strong monitoring from investors, which increases the success rate of early start-ups moving to their next stage of development (Gompers, 1995). Hence, early stage venture capital investment contributes to economic growth via early start-ups creating employment opportunities and undertaking productive economic activities that potentially lead to further investment flows that will spur new innovations. These innovations may be vital for the long-term sustainability of a country's economy.

On the other hand, more mature start-up businesses with an established track record, tend to require late stage VC funding to expand their operations, build new business distribution channels and develop a brand presence. Many of them would require substantial resources to protect their intellectual property and brand image in the global market. These initiatives help

prepare these start-ups for their next stage of evolution, namely going to the capital markets for public funding to strengthen their market competitiveness.

As such, venture capital, both early and late stage funding, are important drivers of economic growth (see, for instance, Keuschnigg, 2004; Samila and Sorenson, 2011). On the other hand, higher economic growth will enable the economy to allocate adequate resources, such as increasing investment in VC funds to help firms acquire new technology and undertake creative endeavors to enhance their competitive position. In this context, economic growth is seen to have a significant and positive impact on venture capital investment (see, for instance, Gompers and Lerner, 1998; Fuss and Schweizer, 2012; Carvell et al., 2013). Thus, we test the following null hypothesis:

H_{1AB}: VC investment Granger-causes economic growth and vice-versa.

***Second, the link between innovation and economic growth*:**

Innovation contributes to economic growth via two major channels. Firstly, innovation leads to the discovery of new technology, systems and processes that improve both productivity and efficiency within the economy. Secondly, innovation is critical for the development of new value-added products and services, contributing to new income generation channels. Several empirical studies have shown that innovation has a significant impact on economic growth (see, for instance, Agenor and Neanidis, 2015; Guloglu and Tekin, 2012; Kirchhoff et al., 2007).

There have been studies that show that economic growth has a significant impact on innovation (see, for instance, Furman et al., 2002; Grossman and Helpman, 1991; Guloglu and Tekin, 2012). The rationale for these causal linkages is that as a country's wealth increases, investment to improve the national innovation ecosystems also increases. In this context, investment for education, R&D, technology development and other incentives to create a business-friendly environment are created – all of which increase the innovation levels of the country. Thus, we test the following null hypothesis:

H_{2AB}: Innovation Granger-causes economic growth and vice versa.

***Third, the link between financial development and economic growth*:**

The literature generally supports the notion that financial development has a significant impact on economic growth (see, for instance, Asghar and Hussain, 2014; and Chaiechi, 2012). These studies suggest that a sound financial system leads to an efficient allocation of capital, which in turn contributes to positive economic outcomes. Other studies show that economic growth also has a significant impact on financial development (see, for example, Kar et al., 2011; and Levine, 1997). This suggests that as a nation's wealth increases, the demand for more sophisticated and advanced financial services will increase. Thus, we test the following null hypothesis:

H_{3AB}: Financial development Granger-causes economic growth and vice-versa.

***Fourth, the link between venture capital investment and innovation*:**

Several studies show that the venture capital industry provides an alternate source of financing and other support services to enhance the innovative endeavours of firms (see, for example, Kortum and Lerner, 2000; Berger and Schaeck, 2011; Faria and Barbosa, 2014; Pradhan et al., 2017). Early stage VC funding provides firms with an opportunity to invest in much-needed R&D to improve their technology or intellectual property (IP) in order to be of commercial value and globally competitive. Later stage VC funding is often used by more mature start-up businesses to undertake not only product and process innovations, but also innovations to improve their business models, marketing strategies, supply networks and brand image.

Other studies show that high returns on investment from innovative endeavours in many of the high-tech sectors have led to growth in the venture capital industry (both for the early stage and late stage VC funding) as an alternate source of financing for innovative start-up firms with

high growth potential (Hirukawa and Ueda, 2011; and Geronikolaou and Papachristou, 2012). Thus, we test the following null hypothesis:

H_{4AB}: VC investment Granger-causes innovation and vice-versa.

Fifth, the link between venture capital investment* and *financial development:

Several studies support the idea that venture capital has a significant impact on financial development, and financial development also equally causes VC investment (see, for instance, Chemmanur, 2010; Groh and Wallmeroth, 2016; Obrimah, 2016; Rosenbusch et al., 2013). Both early stage and later stage VC funding contribute to the development of financial sectors in different ways. In the early stage of a startup operation, the probability of failure is rather high. As such, a venture capitalist will expect a higher return and will put in greater effort to ensure the success of the business venture. This is consistent with *Agency Theory*, which suggests higher agency costs are commensurate with higher rates of return.

In the context of mature start-ups with an improved track record, the risk of failure is lower. Hence, the returns obtained by these venture capitalists are lower than that of early stage venture capitalists (Elango et al., 1995). The discussions above suggest that a developed VC industry is able to provide a wide range of financial services based on the risk profile of the start-up businesses.

The results from the studies above highlight that the development of the venture capital industry as an alternative source of capital for innovative firms will intensify competition for viable and sustainable enterprises (as clients) within the financial system. This will force other financial institutions to raise their competitiveness by enhancing product lines and service quality. As the financial sector intensifies its development, the overall governance, transparency and regulatory environment within the financial ecosystem will improve, thus providing a wider choice of financing, including venture capital, for the business community. Thus, we test the following null hypothesis:

H_{5AB}: VC investment Granger-causes financial development and vice-versa.

Sixth, the link between innovation and financial development:

A few recent studies support the notion that innovation has a significant impact on financial development, and financial development also equally causes innovation (see, for example, Hanley et al., 2011; Hsu et al., 2014; Pradhan et al., 2016b). These studies highlight that innovation-led productivity will have positive spillover benefits for the financial sector in the form of improved quality of services, and, potentially, the introduction of new financial instruments and services. Similarly, development in the financial system in the form of more efficient and transparent financial processes will enable firms to make informed financial decisions to mitigate and manage risks. The reduction in asymmetric information and risks will then increase innovative endeavors among firms and financial institutions. Thus, we test the following null hypothesis:

H_{6AB}: Innovation Granger-causes financial development and vice-versa.

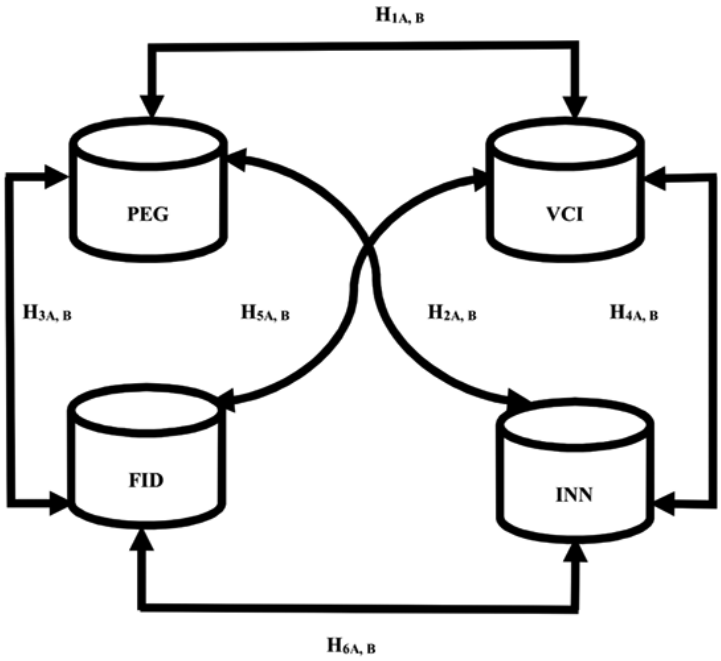
The null hypotheses tested in this paper are summarized in Figure 1.

3.2 Data and Variables

We use annual time series data for 23 European countries[8] over the period 1989 to 2015. The data is obtained from the World Bank's *World Development Indicators* and from the European Venture Capital Association's *Venture Capital Database*.

[8] The countries are Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland, and the United Kingdom.

Figure 1. Possible Causal Relationships and the Hypotheses



Note 1: PEG is per capita economic growth, VCI is venture capital investment, FID is the composite index of financial development, and INN is innovation.

Note 2: VCI has three indicators; INN includes several innovation indicators, used both individually and as a composite index.

Note 3:

$H_{1A, B}$: VC investment Granger-causes economic growth and vice versa.

$H_{2A, B}$: Innovation Granger-causes economic growth and vice versa.

$H_{3A, B}$: Financial development Granger-causes economic growth and vice versa.

$H_{4A, B}$: VC investment Granger-causes innovation and vice versa.

$H_{5A, B}$: VC investment Granger-causes financial development and vice versa.

$H_{6A, B}$: Innovation Granger-causes financial development and vice versa.

The study uses real per capita economic growth (PEG), three different indicators for the venture capital investments (early stage, later stage and total VC investments)[9], and nine different indicators of innovation[10] (INN). In addition, we construct an index of financial development (FID) using eleven different indicators of financial development[11].

VCI comprises venture capital at early stage investment (VCE[12]), measured as a percentage of real gross domestic product (GDP); venture capital at later stage investment (VCL[13]), measured as a percentage of real GDP; and total venture capital, a combination of both early stage and later stage investments (VCT), measured as a percentage of real GDP.

INN includes the number of patents by residents per thousand population (PAR), the number of patents by non-residents per thousand population (PAN), researchers engaged in R&D activities per million population (RRD), scientific and technical journal articles per thousand of population (STJ), trademark applications by residents per thousand population (TRR), trademark applications by non-residents per thousand population (TRN), real R&D expenditure as a percentage of real GDP (RDE), and high technology real exports as a percentage of real GDP (HTE). In addition to utilizing these eight individual measures of INN, we also construct and use a composite index of innovation (CII), which is a weighted average of eight individual innovation indicators. The index can harness the richness of information and can capture all aspects of innovation. Thus, in all, nine measures of innovation are evaluated.

Financial development is captured through a composite index (FID), which is the weighted average of eleven financial development indicators, including both banking sector and

[9] The proxies for venture capital investment have previously been used by Faria and Barbosa (2014).

[10] These proxies for innovation have previously been used by Pradhan et al. (2016a).

[11] These proxies for financial development have previously been used by Pradhan et al. (2016b).

[12] VCE is the level of investment performed by venture capital firms towards young businesses in their primary development stage.

[13] VCL is the level of investment performed by venture capital firms towards young businesses in need of expansion capital.

stock market indicators. These indicators are central bank assets (CBA), deposit money bank assets to money bank assets and central bank assets (DBA), deposit money bank assets and central bank assets (DBT), domestic credit to private sector (DCP), liquid liabilities (LIQ), private credit by deposit money banks and other financial institutions (PCO), private credit deposit money banks (PCM), market capitalization (MAC), traded stocks (TRA), turnover (TUR), and number of listed companies (LDC).

The idea of forming a composite index is not new as composite indices have been used in many earlier research papers for different reasons. We construct our composite indices as per the OECD recommended procedures (OECD, 2008). Appendix B provides a detailed discussion of the construction of our two indices (see Table B.1 for our innovation index (CII) and Table B.2 for our financial development index (FID)). Appendix C defines the variables that are used in this study, while Appendix D provides the descriptive statistics and the correlation matrix of the variables.[14]

For total venture capital investment, we evaluate nine cases based on our measures of innovation. Case 1 uses the number of resident patents (PAR); case 2 uses the number of non-resident patents (PAN); case 3 uses researchers in R&D activities (RRD); case 4 uses scientific and technical journal articles (STJ); case 5 uses the number of resident trademark applications; case 6 uses the number of non-resident trademark applications, case 7 uses R&D expenditure (RDE); case 8 uses high-technology exports (HTE); and case 9 uses the composite index of innovation (CII). The idea of nine cases under each specification is to test the robustness of our results concerning the interaction between the four variables and to contrast the short-run with long-run results.

[14] Logarithmic forms of the variables are used in the statistical analysis here.

3.3 Econometric Model

Following Holtz-Eakin et al. (1988), we deploy the following dynamic panel VECM[15] to inspect the possible directions of causality between venture capital investment, innovation, financial development, and per capita economic growth.

$$\begin{bmatrix} \Delta Per\ capita\ economic\ growth_{it} \\ \Delta Venture\ capital\ investment_{it} \\ \Delta Innovation_{it} \\ \Delta Finnacial\ development_{it} \end{bmatrix} = \begin{bmatrix} \alpha_{1j} \\ \alpha_{2j} \\ \alpha_{3j} \\ \alpha_{4j} \end{bmatrix} + \sum_{k=1}^{q} \begin{bmatrix} \beta_{11ik}(L)\ \beta_{12ik}(L)\ \beta_{13ik}(L)\ \beta_{14ik}(L) \\ \beta_{21ik}(L)\ \beta_{22ik}(L)\ \beta_{23ik}(L)\ \beta_{24ik}(L) \\ \beta_{31ik}(L)\ \beta_{32ik}(L)\ \beta_{33ik}(L)\ \beta_{34ik}(L) \\ \beta_{41ik}(L)\ \beta_{42ik}(L)\ \beta_{43ik}(L)\ \beta_{44ik}(L) \end{bmatrix} \begin{bmatrix} \Delta Per\ capita\ economic\ growth_{it-k} \\ \Delta Venture\ capital\ investment_{it-k} \\ \Delta Innovation_{it-1} \\ \Delta Financial\ development_{it-k} \end{bmatrix} + \begin{bmatrix} \eta_{1i} ECT_{it-1} \\ \eta_{2i} ECT_{it-1} \\ \eta_{3i} ECT_{it-1} \\ \eta_{4i} ECT_{it-1} \end{bmatrix} + \begin{bmatrix} \xi_{1it} \\ \xi_{2it} \\ \xi_{3it} \\ \xi_{4it} \end{bmatrix} \quad \textbf{(1)}$$

where Δ is the first difference operator, *i* denotes the country and *t* the year in the panel, and ξ is the random error term. *Venture capital investment* is defined as VCT, while *innovation* is defined as PAR, PAN, RRD, STJ, TRR, TRN, RDE, HTE, or CII, and *financial development* is defined as FID.

The ECT_{-1}'s are the lagged error-correction terms. The above VECM provides robust results if the time series variables are integrated of order one and cointegrated. If the

[15] VECM is used to examine possible Granger causal relationships among the variables as well as explain the variance of one variable (say per capita economic growth) through the other three variables (venture capital investment, financial development, and innovation).

variables used in VECM are not cointegrated, the lagged error-correction terms are removed in the estimation process.

The choice of the lag length is an important consideration in a VECM estimation process, as the causality test results depend on the lag specification. Typically, both too few and too many lags may pose problems. On the one hand, short lag lengths suggest that some important variables may have been omitted from the model, and this type of specification error normally causes bias in the regression coefficients that are obtained, leading to misleading inferences. In contrast, long lag lengths will reduce the degrees of freedom and will usually increase the standard error of the estimated coefficients, making the estimates less reliable.

Unfortunately, there is no universal rule for deciding the optimum lag lengths. One way to proceed would be to allow the lag structure to vary across both countries and variables. However, given that we are dealing with several specifications/cases as well as a large panel, this would substantially increase the computational burden. For this reason, in estimating equation (1), we allow different maximum lag lengths for the variables, but do not allow them to vary across countries. This study uses HQIC[16] statistics to select the optimum lag length.

4. EMPIRICAL RESULTS

We utilize a dynamic panel vector error-correction model to examine the possible Granger causal relationships between our variables. Before we proceed, we have to

[16] HQIC denotes the Hannan-Quinn Information Criterion and it is most appropriate for choosing the optimum lag length. As this criterion is explained in many econometrics textbooks, we will not detail it here.

identify the order of integration and establish the nature of cointegration among the four sets of variables.

We use five different panel unit root tests[17] with individual intercepts to examine the order of integration of the variables in our panel setting. The results of these tests are reported in Table 1. These tests confirm that all the variables are integrated of order one, i.e., I (1). As the test-statistics of the unit root test at levels are below the critical values for all the various approaches, the null hypothesis of unit root at the 1% significance level is accepted. However, as the test-statistics of the unit root test in first difference are above the critical values for all the approaches, the null hypothesis of unit root at the 1% significance level is rejected so that the variables are integrated of order one (see the results in Table 1). These results reveal that there is the possibility of cointegration among venture capital investment (early stage, later stage and total venture capital investments), innovation, financial development, and per capita economic growth.

A panel cointegration test, namely the Pedroni (1999) test with individual intercepts, is employed to test the hypothesis that a long-run relationship exists between venture capital investment, innovation, financial development, and per capita economic growth. The results of this test are reported in Table 2. In nearly every case the null hypothesis of no-cointegration is rejected by most of these test statistics at the 1% level (see Table 2 for the cases: VCT, VCE and VCL, respectively). Hence, this confirms the

[17] The unit root tests are the Levin-Lin-Chu '*t*-stat' test (LLC test; Levin et al., 2002), the Breitung '*t*-stat' test (BR test; *Breitung*, 2000), the Im-Pesaran-Shin '*W*-stat' test (IPS test; Im et al., 2003), the Augmented Dickey Fuller(ADF) -Fisher 'Chi-Square' test, and the Phillips Perron (PP) -Fisher 'Chi-Square' test (Choi, 2001). These five tests are explained in advanced econometric textbooks and are not described here due to space constraints.

Table 1: Results of Panel Unit Root Tests

Variable	Level	Test Statistics				
		LLC	**BT**	**IPS**	**ADF**	**PP**
Part A: Economic Growth Indicator						
PEG	**0**	9.51	5.26	0.72	21.2	92.5
	1	-3.91***	-3.09***	-6.87***	120.8***	183.3***
Part B: Financial Development Indicator						
FID	**0**	1.63	4	0.05	49.1	50.2
	1	-6.99***	-1.68**	-5.27***	108.0***	113.2***
Part C: Venture Capital Indicators						
VCE	**0**	0.34	-0.37	-0.1	28	33.9
	1	-9.25***	-4.65***	-2.79***	66.2***	440.9***
VCL	**0**	1.42	0.32	0.73	26.9	57.3
	1	-2.80***	-5.02***	-5.39***	116.5***	311.4***
VCT	**0**	1.74	-0.69	2.73	13	36.7
	1	-4.47***	-7.80***	-7.58***	129.7***	395.9***
Part D: Innovation Indicators						
PAR	**0**	1.3	2.28	2.11	25.3	42.3
	1	-5.69***	-3.87***	-5.90***	104.2***	212.0***
PAN	**0**	0.22	-0.35	0.08	45.4	55.4
	1	-10.2***	-3.34***	-7.07***	156.5***	181.6***
RRD	**0**	-0.42	1.24	1.16	24.8	52.2
	1	-5.44***	-3.60***	-2.05*	62.6***	181.5***
STJ	**0**	7.15	-0.49	2.83	12.4	37.1
	1	-2.27**	-5.89***	-4.28***	75.8***	243.8***
TRR	**0**	-0.02	0.39	-0.16	30.6	43.3
	1	-2.22**	-3.13***	-3.63***	61.9***	193.9***
TRN	**0**	1.87	0.82	0.72	26.2	59.9
	1	-2.79***	-4.76***	-3.58***	64.3***	492.5***
RDE	**0**	-0.03	-0.18	0.05	37.8	27.3
	1	-4.41***	-3.96***	-2.43***	68.2***	111.3***
HTE	**0**	-0.41	0.44	1.01	27.8	33.8
	1	-5.06***	-5.91***	-5.76***	101.1***	218.5***
CII	**0**	25.5	19.8	11.6	7.29	2.67
	1	-6.85***	-9.73***	-5.48***	66.7***	80.67***

Note 1: PEG is per capita economic growth, VCE is venture capital at early stage investment, VCL is venture capital at later stage investment, VCT is venture capital total investment, FID is the composite index of financial development, PAR is the number of patents- residents, PAN is the number of patents - non-residents; RRD is researchers in research and development activities, STJ is scientific and technical journal articles, TRR is trademark applications- residents, TRN is trademark applications- non-residents, RDE is the research and development expenditure, HTE is high-technology exports, and CII is the composite index of innovation.

Note 2: The LLC, BT, IPS, ADF, and PP tests are explained in footnote 17.

Note 3**:** ******,*** ** and * indicate that the parameter estimates are significant at the 1%, 5% and 10% levels, respectively.

Note 3**:** 0 is level data; I is data at first difference level.

Table 2: Results of Panel Cointegration Test for Various Specifications and Cases

Test Statistics	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
Specification1: PEG, VCE, FID, INN									
Panel υ	2.39***	2.24*	6.83***	2.94***	2.83***	2.32***	1.75**	1.70**	2.62***
Panel ρ	-1.32*	-1.57**	-1.89**	-1.37*	-1.47*	-1.59**	-1.72**	-1.46*	-1.41*
Panel PP	-7.61***	-7.69*	-8.50***	-8.04***	-5.23***	-8.22***	-6.07***	-10.4***	-7.79***
Panel ADF	-4.59***	-4.27*	-3.86***	-5.47***	-3.86***	-5.58***	-3.82***	-7.56***	-4.61***
Group ρ	0.98	0.72	3.28	0.94	0.58	0.68	2.91	0.78	0.66
Group PP	-11.6***	-12.3*	-15.9***	-14.8***	-7.05***	-13.5***	-9.89***	-16.7***	-20.0***
Group ADF	-5.69***	-5.29*	-4.66***	-6.58***	-13.2***	-7.44***	-4.99***	-8.07***	-5.35***
Specification 2: PEG, VCL, FID, INN									
Panel υ	1.67**	1.21*	11.3***	1.68**	1.98**	1.48*	1.24*	1.19*	1.32*
Panel ρ	-1.29*	-1.37*	-1.29*	-1.98**	-1.84**	-1.53***	-1.31*	-1.41*	-1.33*
Panel PP	-6.34***	-6.74***	-6.21***	-6.51***	-7.29***	-6.39***	-3.33***	-8.56***	-6.66***
Panel ADF	-7.44***	-7.26***	-5.62***	-8.34***	-8.11***	-7.75***	-5.20***	-9.25***	-8.30***
Group ρ	1.07	1	2.9	1.16	0.84	0.72	2.65	0.67	0.9
Group PP	-10.5***	-10.3***	-12.4***	-13.0***	-7.94***	-11.8***	-10.1***	-16.3***	-14.4
Group ADF	-6.41***	-6.44***	-5.63***	-9.99***	-9.32***	-7.91***	-5.31***	-9.32***	-7.55***
Specification 3: PEG, VCT, FID, INN									
Panel υ	1.67**	1.29*	7.06***	2.45***	1.29*	1.98**	2.07**	1.81**	1.89**
Panel ρ	-1.35*	-1.22*	-1.23*	-1.29*	-1.57**	-1.28**	-1.23*	-1.21*	-1.28*
Panel PP	-5.90***	-6.23***	-6.64***	-6.00***	-5.57***	-6.55***	-4.94***	-8.36***	-6.57***
Panel ADF	-5.75***	-6.36***	-3.82***	-5.95***	-7.50***	-6.09***	-4.35***	-6.57***	-5.90***
Group ρ	1.23	1.05	3.37	1.44	0.83	0.96	3.03	1.18	1.13
Group PP	-10.4***	-11.3***	-13.6***	-14.2***	-9.02***	-13.8***	-12.0***	-15.3***	-13.1***
Group ADF	-6.71***	-7.33***	-4.70***	-7.44***	-14.5***	-7.83***	-6.73***	-7.94***	-7.32***

***Note 1*:** Case 1: Economic growth, venture capital, FID, and PAR; Case 2: Economic growth, venture capital, FID, and PAN; Case 3: Economic growth, venture capital, FID, and RRD; Case 4: Economic growth, venture capital, FID, and STJ; Case 5: Economic growth, venture capital, FID, and TRR; Case 6: Economic growth, venture capital, FID, and TRN; Case 7: Economic growth, venture capital, FID, and RDE; Case 8: Economic growth, venture capital, FID, and HTE; Case 9: Economic growth, venture capital, FID, and CII.

Note 2: PEG is per capita economic growth, VCE is venture capital at early stage investment, VCL is venture capital at later stage investment, VCT is venture capital total investment, FID is the composite index of financial development, PAR is the number of patents- residents, PAN is the number of patents - non-residents; RRD is researchers in research and development activities, STJ is scientific and technical journal articles, TRR is trademark applications- residents, TRN is trademark applications- non-residents, RDE is the research and development expenditure, HTE is high-technology exports, and CII is the composite index of innovation.

Note 3**:** INN stands for innovation and is used to indicate PAR, PAN, RRD, STJ, TRR, TRN, RDE, HTE, or CII.

Note 4**: ****,*** ** and * indicate that the parameter estimates are significant at the 1%, 5% and 10% levels, respectively.

existence of a long-run equilibrium relationship between the variables in the three specifications and the nine cases that we study.

The findings presented above support the final step in our investigation, which is using a VECM approach to examine the nature of causal relationships among the four sets of variables, the results of which are summarized in Tables 3 and 4 for the nine different cases that we consider. Table 3 presents the statistical results of our VECM estimation, while Table 4 provides the summary of the non-uniform short-run results.

The long-run results are established through examining the statistical significance of the ECT_{-1} coefficients. Table 3 shows that when per capita economic growth (ΔPEG) is used as the dependent variable, the ECT_{-1} coefficients are uniformly statistically significant at the 1% level. This is the case across all of the nine cases. From this, we can infer that per capita economic growth generally converges to its long-run equilibrium path in response to changes in venture capital investment, innovation[18] and financial development. These robust results are supported for all three venture capital investment measures.

We can therefore conclude that per capita economic growth in the selected 23 European countries is significantly influenced by venture capital investment, innovation, and financial development. This suggests that venture capital investments (early stage, later stage and total investments), innovation and financial development support the supply-leading hypothesis (SLH). In other words, in order to propel long-run per capita

[18] As mentioned in Section 3.2, here we use all of the innovation indicators. In contrast to venture capital investment, innovation indicators are completely different and these indicators have different units of measurements and some are input type innovation with different specifications, while others are output type innovation with different specifications. Therefore, it is necessary to test them individually along with a composite index. The use of these innovation indicators do not yield a difference in long-run causality results; however, differences in the short-run results do occur, which are shown below.

Table 3: Results of Panel Granger Causality Test for Various Specifications and Cases

Dependent **Independent Variables and ECT_{-1}**

Specification 1: PEG, VCE, FID, INN

	Case 1					Case 2				
	ΔPEG	**ΔVCE**	**ΔFID**	**ΔPAR**	**ECT_{-1}**	**ΔPEG**	**ΔVCE**	**ΔFID**	**ΔPAN**	**ECT_{-1}**
ΔPEG	------	6.77**	2.21	1.17	-0.67***	------	8.15***	1.51	1.03	-0.67***
ΔVCE	0.74	------	6.56**	3.53	-0.16	0.38	------	6.72**	4.49*	-0.19
ΔFID	0.43	0.05	------	0.19	-0.11	0.77	0.02	------	0.44	-0.13
ΔINN	25.4***	5.31**	0.56	------	-0.03	6.94**	7.18**	1.84	------	-0.07

	Case 3					Case 4				
	ΔPEG	**ΔVCE**	**ΔFID**	**ΔRRD**	**ECT_{-1}**	**ΔPEG**	**ΔVCE**	**ΔFID**	**ΔSTJ**	**ECT_{-1}**
ΔPEG	------	5.47**	0.81	8.59***	-0.74***	------	5.66**	2.23	0.62	-0.74***
ΔVCE	0.85	------	4.46*	4.98*	-0.45	0.11	------	4.45*	14.1***	-0.11
ΔFID	1.19	3.74	------	0.91	-0.15	0.33	0.3	------	2.97	-0.08
ΔINN	1.27	1.5	0.36	------	-0.03	2.99	16.3***	43.2***	------	-0.04

	Case 5					Case 6				
	ΔPEG	**ΔVCE**	**ΔFID**	**ΔTRR**	**ECT_{-1}**	**ΔPEG**	**ΔVCE**	**ΔFID**	**ΔTRN**	**ECT_{-1}**
ΔPEG	------	15.7***	2.41	10.9***	-0.74***	------	6.03**	1.01	3.4	-0.72***
ΔVCE	0.4	------	6.70**	1.28	-0.16	0.13	------	6.61**	14.1*	-0.31
ΔFID	0.35	0.05	------	0.03	-0.11	2.85	1.21	------	26.9*	-0.18
ΔINN	1.62	2.07	0.25	------	-0.3	1.97	0.13	1.58	------	-0.06

	Case 7					Case 8				
	ΔPEG	**ΔVCE**	**ΔFID**	**ΔRDE**	**ECT_{-1}**	**ΔPEG**	**ΔVCE**	**ΔFID**	**ΔHTE**	**ECT_{-1}**
ΔPEG	------	4.91*	1.03	2.69	-0.68***	------	8.11***	4.46*	29.6***	-0.70***
ΔVCE	0.34	------	6.88**	1.71	-0.42	0.11	------	6.21***	3.1	-0.07
ΔFID	1.4	11.7***	------	0.59	-0.19	0.46	0.32	------	3.42	-0.09
ΔINN	24.9***	2.12	0.4	------	-0.02	5.96**	8.85***	4.53*	------	-0.17

	Case 9				
	ΔPEG	**ΔVCE**	**ΔFID**	**ΔCII**	**ECT_{-1}**
ΔPEG	------	6.15***	1.73	2.91	-0.69***
ΔVCE	0.49	------	7.54***	19.1***	-0.31
ΔFID	1.54	0.72	------	33.2***	-0.19
ΔINN	2.41	1.99	1.9	------	-0.06

Specification 2: PEG, VCL, FID, INN

	Case 1					Case 2				
	ΔPEG	**ΔVCL**	**ΔFID**	**ΔPAR**	**ECT_{-1}**	**ΔPEG**	**ΔVCL**	**ΔFID**	**ΔPAN**	**ECT_{-1}**
ΔPEG	------	8.02***	1.11	0.04	-0.58***	------	8.81***	0.43	1.82	-0.56***
ΔVCL	4.98*	------	2.8	1.07	-0.08	4.68*	------	3.01	0.34	-0.03
ΔFID	1.16	2.84	------	0.37	-0.16	1.33	2.79	------	0.25	-0.17

ΔINN	4.72*	0.22	0.11	------	-0.05	7.43**	1.15	1.97	------	-0.16

			Case 3					**Case 4**		
	ΔPEG	**ΔVCL**	**ΔFID**	**ΔRRD**	**ECT$_{-1}$**	**ΔPEG**	**ΔVCL**	**ΔFID**	**ΔSTJ**	**ECT$_{-1}$**
ΔPEG	------	15.3***	0.75	8.50***	-0.65***	------	9.71***	0.65	0.59	-0.59***
ΔVCL	2.84	------	1.96	2.9	-0.2	5.17*	------	1.74	6.59**	-0.19
ΔFID	1.23	3.51	------	0.2	-0.15	1.3	3.52	------	2.77	-0.15
ΔINN	2.17	5.80**	0.54	------	-0.03	4.67*	2.81	35.1***	------	-0.14

			Case 5					**Case 6**		
	ΔPEG	**ΔVCL**	**ΔFID**	**ΔTRR**	**ECT$_{-1}$**	**ΔPEG**	**ΔVCL**	**ΔFID**	**ΔTRN**	**ECT$_{-1}$**
ΔPEG	------	8.22***	1.28	12.7***	-0.58***	------	8.27***	0.79	1.61	-0.57***
ΔVCL	5.10*	------	2.8	7.22***	-0.1	3.35	------	1.98	22.6***	-0.16
ΔFID	1.11	2.72	------	0.01	-0.14	4.47*	4.72*	------	30.0***	-0.27
ΔINN	6.07**	1.88	0.33	------	-0.84	2.03	7.10**	1.38	------	-0.03

			Case 7					**Case 8**		
	ΔPEG	**ΔVCL**	**ΔFID**	**ΔRDE**	**ECT$_{-1}$**	**ΔPEG**	**ΔVCL**	**ΔFID**	**ΔHTE**	**ECT$_{-1}$**
ΔPEG	------	11.3***	0.68	1.07	-0.67***	------	8.53***	2.89	23.9***	-0.62***
ΔVCL	2.39	------	3.41	0.44	-0.49	3.46	------	1.75	1.95	-0.04
ΔFID	1.81	19.7***	------	4.47*	-0.3	0.3	2.01	------	2.36	-0.14
ΔINN	1.82	0.17	0.72	------	-0.03	1.05	1.86	2.07	------	-0.1

			Case 9		
	ΔPEG	**ΔVCL**	**ΔFID**	**ΔCII**	**ECT$_{-1}$**
ΔPEG	------	14.9***	0.71	0.79	-0.55***
ΔVCL	6.61**	------	2.84	5.30*	-0.31
ΔFID	2.46	3.54	------	27.4***	-0.28
ΔINN	12.9***	2.12	0.97	------	-0.36

Specification 3: PEG, VCT, FID, INN

			Case 1					**Case 2**		
	ΔPEG	**ΔVCT**	**ΔFID**	**ΔPAR**	**ECT$_{-1}$**	**ΔPEG**	**ΔVCT**	**ΔFID**	**ΔPAN**	**ECT$_{-1}$**
ΔPEG	------	8.68***	3.66	1.91	-0.71***	------	10.9***	2.45	1.32	-0.70***
ΔVCT	1.51	------	4.83***	2.96	-0.4	1.4	------	4.85*	3.01	-0.42
ΔFID	0.57	4.98*	------	0.22	-0.11	0.99	4.97*	------	0.3	-0.14
ΔINN	24.0***	1.44	0.11	------	-0.05	6.56**	1.5	2.1	------	-0.09

			Case 3					**Case 4**		
	ΔPEG	**ΔVCT**	**ΔFID**	**ΔRRD**	**ECT$_{-1}$**	**ΔPEG**	**ΔVCT**	**ΔFID**	**ΔSTJ**	**ECT$_{-1}$**
ΔPEG	------	24.7***	2.17	5.74**	-0.74***	------	10.1***	3.02	0.44	-0.78***
ΔVCT	1.09	------	4.91*	0.1	-0.5	0.59	------	3.49	5.43**	-0.34
ΔFID	1.55	3.39	------	0.52	-0.16	0.47	5.68**	------	3.50*	-0.1
ΔINN	0.53	2.21	0.85	------	-0.02	4.65*	4.45*	34.8***	------	-0.05

Case 5 **Case 6**

	ΔPEG	ΔVCT	ΔFID	ΔTRR	ECT_{-1}	ΔPEG	ΔVCT	ΔFID	ΔTRN	ECT_{-1}
ΔPEG	------	16.4***	4.12	12.7***	-0.78***	------	7.84***	2.63	5.54***	-0.74***
ΔVCT	0.29	------	4.82*	6.72***	-0.28	0.64	------	4.95*	24.2***	-0.49
ΔFID	0.37	1.93	------	0.06	-0.12	2.74	3.01	------	27.5***	-0.19
ΔINN	1.97	1.52	0.14	------	-0.35	1.99	6.36***	1.6	------	-0.05

	Case 7					Case 8				
	ΔPEG	**ΔVCT**	**ΔFID**	**ΔRDE**	**ECT_{-1}**	**ΔPEG**	**ΔVCT**	**ΔFID**	**ΔHTE**	**ECT_{-1}**
ΔPEG	------	14.3***	0.8	1.08	-0.74***	------	8.38***	5.96***	30.3***	-0.73***
ΔVCT	0.56	------	4.35*	4.43*	-0.37	0.7	------	5.63***	4.86*	-0.4
ΔFID	3.34	15.9***	------	2.2	-0.25	0.92	3.42	------	2.21	-0.12
ΔINN	32.9***	9.80***	0.64	------	-0.04	4.87*	2.56	1.07	------	-0.15

	Case 9				
	ΔPEG	**ΔVCT**	**ΔFID**	**ΔCII**	**ECT_{-1}**
ΔPEG	------	11.2***	2.57	2.62	-0.74***
ΔVCT	1.68	------	5.84**	16.2***	-0.54
ΔFID	1.82	5.98**	------	34.9***	-0.2
ΔINN	3.03	0.29	1.64	------	-0.08

***Note 1*:** Case 1: Economic growth, venture capital, FID, and PAR; Case 2: Economic growth, venture capital, FID, and PAN; Case 3: Economic growth, venture capital, FID, and RRD; Case 4: Economic growth, venture capital, FID, and STJ; Case 5: Economic growth, venture capital, FID, and TRR; Case 6: Economic growth, venture capital, FID, and TRN; Case 7: Economic growth, venture capital, FID, and RDE; Case 8: Economic growth, venture capital, FID, and HTE; Case 9: Economic growth, venture capital, FID, and CII.

Note 2: PEG is per capita economic growth, VCE is venture capital at early stage investment, VCL is venture capital at later stage investment, VCT is venture capital total investment, FID is the composite index of financial development, PAR is the number of patents- residents, PAN is the number of patents- non-residents; RRD is researchers in research and development activities, STJ is scientific and technical journal articles, TRR is trademark applications- residents, TRN is trademark applications- non-residents, RDE is the research and development expenditure, HTE is high-technology exports, CII is the composite index of innovation, and ECT_{-1} is lagged error-correction term.

***Note 3*:** INN stands for innovation and is used to indicate PAR, PAN, RRD, STJ, TRR, TRN, RDE, HTE, or CII.

Note 4*: *,*** ** and * indicate that the parameter estimates are significant at the 1%, 5% and 10% levels, respectively.

economic growth, it is important to elevate venture capital investment, innovation, and financial development in European countries.

We summarize the short-run Granger causality results in support of various hypotheses in Table 4 for the three venture capital measures (VCT, VCE and VCL) and the nine innovation indicators (PAR, PAN, RRD, STJ, TRR, TRN, RDE, HTE, and CII). The short-run relationships between the variables are stated below.

- *Venture capital and economic growth*: when VCE and VCT are considered, all nine innovation indicators support SLH (VC to growth). On the other hand, when VCL is considered, only four out of the nine innovation indicators support SLH while four support FBH (the feedback hypothesis). In the case of CII, the VCL supports FBH.
- *Financial development and economic growth*: a majority of the innovation indicators, including CII for VCE, VCL and VCT support NEH (the neutrality hypothesis).
- *Innovation and economic growth*: There are significant variations in the results based on the innovation indicators used in the models. In the case of VCE, three out of the nine innovation indicators (PAR, PAN and RDE) support DFH (the demand-following hypothesis) from growth to innovation; two indicators (RRD and TRR) support SLH (innovation to growth); two indicators (STI and TRN) support NEH; one indicator (HTE) supports FBH. The composite innovation index supports NEH.

  In the case of VCL, three out of the nine indicators (PAR, PAN and STI) support DFH (growth to innovation); two indicators (RRD and HTE) support SLH (innovation to growth); two indicators (TRN and RDE) support NEH;

one indicator (TRR) supports FBH. The composite innovation index supports DFH (growth to innovation).

In the case of VCT, four out of the nine indicators (PAR, PAN, STI and RDE) support DFH (growth to innovation); three indicators (RRD, TRR and TRN) support SLH (innovation to growth); and one indicator (HTE) supports FBH. The composite innovation indicator supports NEH.

- *Venture capital and financial development*: In the case of VCE, the majority of the innovation indicators (eight out of nine) support DFH (financial development to VC). In the case of VCL, the majority of the innovation indicators (seven out of nine) support NEH. In the case of VCT, four indicators (RRD, TRR, TRN and THE) support DFH (financial development to VC); three indicators (PAR, PAN and RDE) support FBH; one indicator (STI) supports SLH (VC to financial development); and the composite innovation indicator supports FBH.
- *Venture capital and innovation*: In the case of VCE, two indicators (PAR and HTE) support SLH (VC to innovation); two indicators (RRD and TRN) support DLH (innovation to VC); two indicators (PAN and STI) support FBH; two indicators (TRR and RDE) support NEH; and the composite innovation indicator (CII) supports DFH (innovation to VC).

  In the case of VCL, four indicators (PAR, PAN, RDE and HET) support NEH; two indicators (STI and TRR) support DFH (innovation to VC); one indicator (RRD) supports SLH (VC to innovation) and one indicator (TRN) supports FBH; and the composite innovation indicator (CII) supports DFH (innovation to VC).

- *Financial development and innovation:* In the case of VCE, the majority of the innovation indicators (PAR, PAN, RRD, TRR, and RDE) support NEH; two indicators (STI and HET) support DFH (financial development to innovation); and one indicator (TRN) supports SLH (innovation to financial development); while the composite innovation indicator (CII) supports SLH (innovation to financial development). Similar results were also observed for VCL and VCT, where a majority of the innovation indicators, including the composite innovation indicator support SLH (innovation to financial development).

In summary, the short-run analysis shows that there are complex relationships among VC, financial development, innovation and economic growth based on the types of innovation indicators and venture capital measures used in these models. The short-run analysis suggests that there are strong endogenous relationships between the four variables.

Some supplementary results, though not discussed at length due to space constraints, deserve a brief discussion. Firstly, in order to check the robustness of our results, we obtained additional estimates using the FMOLS[19] and DOLS[20] methodologies. The results of these two estimations are consistent with our long-run causality results, indicating that venture capital investment, innovation and financial development have a

[19] FMOLS is fully modified ordinary least squares (OLS), a non-parametric estimation approach, taking into account the feasible correlation between the error term and the first differences of the regressor as well as the presence of a constant term to deal with corrections for serial correlation (see, *inter alia*, Maeso-Fernandez et al., 2006; Pedroni, 2000).

[20] DOLS is dynamic OLS, a parametric estimation approach that adjusts the errors by augmenting the static regression with leads, lags, and contemporaneous values of the regressor in first differences (see, *inter alia*, Kao and Chiang, 2000).

Table 4: Summary of Short-run Granger Causality Results

Scenarios	Cases	Short-Run Causal Links					
		VCI & PEG	**FID & PEG**	**INN & PEG**	**VCI & FID**	**VCI & INN**	**FID & INN**
	1	SLH[a]	NEH[b]	DFH[c]	DFH[d]	SLH[e]	NEH[f]
	2	SLH[a]	NEH[b]	DFH[c]	DFH[d]	FBH[e]	NEH[f]
	3	SLH[a]	NEH[b]	SLH[c]	DFH[d]	DFH[e]	NEH[f]
	4	SLH[a]	NEH[b]	NEH[c]	DFH[d]	FBH[e]	DFH[f]
VCE	**5**	SLH[a]	NEH[b]	SLH[c]	DFH[d]	NEH[e]	NEH[f]
	6	SLH[a]	NEH[b]	NEH[c]	DFH[d]	DFH[e]	SLH[f]
	7	SLH[a]	NEH[b]	DFH[c]	FBH[d]	NEH[e]	NEH[f]
	8	SLH[a]	SLH[b]	FBH[c]	DFH[d]	SLH[e]	DFH[f]
	9	SLH[a]	NEH[b]	NEH[c]	DFH[d]	DFH[e]	SLH[f]
	1	FBH[a]	NEH[b]	DFH[c]	NEH[d]	NEH[e]	NEH[f]
	2	FBH[a]	NEH[b]	DFH[c]	NEH[d]	NEH[e]	NEH[f]
	3	SLH[a]	NEH[b]	SLH[c]	NEH[d]	SLH[e]	NEH[f]
	4	FBH[a]	NEH[b]	DFH[c]	NEH[d]	DFH[e]	DFH[f]
VCL	**5**	FBH[a]	NEH[b]	FBH[c]	NEH[d]	DFH[e]	NEH[f]
	6	SLH[a]	DFH[b]	NEH[c]	SLH[d]	FBH[e]	SLH[f]
	7	SLH[a]	NEH[b]	NEH[c]	SLH[d]	NEH[e]	SLH[f]
	8	SLH[a]	NEH[b]	SLH[c]	NEH[d]	NEH[e]	NEH[f]
	9	FBH[a]	NEH[b]	DFH[c]	NEH[d]	DFH[e]	SLH[f]
	1	SLH[a]	NEH[b]	DFH[c]	FBH[d]	NEH[e]	NEH[f]
	2	SLH[a]	NEH[b]	DFH[c]	FBH[d]	NEH[e]	NEH[f]
	3	SLH[a]	NEH[b]	SLH[c]	DFH[d]	NEH[e]	NEH[f]
	4	SLH[a]	NEH[b]	DFH[c]	SLH[d]	FBH[e]	FBH[f]
VCT	**5**	SLH[a]	NEH[b]	SLH[c]	DFH[d]	DFH[e]	NEH[f]
	6	SLH[a]	NEH[b]	SLH[c]	DFH[d]	FBH[e]	SLH[f]
	7	SLH[a]	NEH[b]	DFH[c]	FBH[d]	FBH[e]	NEH[f]
	8	SLH[a]	SLH[b]	FBH[c]	DFH[d]	DFH[e]	NEH[f]
	9	SLH[a]	NEH[b]	NEH[c]	FBH[d]	DFH[e]	SLH[f]

***Note 1*:** Case 1: Economic growth, venture capital, FID, and PAR; Case 2: Economic growth, venture capital, FID, and PAN; Case 3: Economic growth, venture capital, FID, and RRD; Case 4: Economic growth, venture capital, FID, and STJ; Case 5: Economic growth, venture capital, FID, and TRR; Case 6: Economic growth, venture capital, FID, and TRN; Case 7: Economic growth, venture capital, FID, and RDE; Case 8: Economic growth, venture capital, FID, and HTE; Case 9: Economic growth, venture capital, FID, and CII.

Note 2: PEG is per capita economic growth, VCE is venture capital at early stage investment, VCL is venture capital at later stage investment, VCT is venture capital total investment, FID is the composite index of financial development, PAR is the number of patents- residents, PAN is the number of patents - non-residents; RRD is researchers in research and development activities, STJ is scientific and technical journal articles, TRR is trademark applications- residents, TRN is trademark applications- non-residents, RDE is the research and development expenditure, HTE is high-technology exports, CII is the composite index of innovation, and ECT_{-1} is lagged error-correction term.

***Note 3*:**

SLH^a is supply-leading hypothesis of VC-growth nexus (VC to growth), DFH^a is demand-following hypothesis of VC-growth nexus (growth to VC), FBH^a is feedback hypothesis of VC-growth nexus, and NEH^a is neutrality hypothesis of VC-growth nexus.

SLH^b is supply-leading hypothesis of financial development-growth nexus (financial development to growth), DFH^b is demand-following hypothesis of financial development-growth nexus (growth to financial development), FBH^b is feedback hypothesis of financial development-growth nexus, and NEH^b is neutrality hypothesis of financial development-growth nexus.

SLH^c is supply-leading hypothesis of innovation-growth nexus (innovation to growth), DFH^c is demand-following hypothesis of innovation-growth nexus (growth to innovation), FBH^c is feedback hypothesis of innovation-growth nexus, and NEH^c is neutrality hypothesis of innovation-growth nexus.

SLH^d is supply-leading hypothesis of VC-financial development nexus (VC to financial development), DFH^d is demand-following hypothesis of VC-financial development nexus (financial development to VC), FBH^d is feedback hypothesis of VC-financial development nexus, and NEH^d is neutrality hypothesis of VC-financial development nexus.

SLH^e is supply-leading hypothesis of VC-innovation nexus (VC to innovation), DFH^e is demand-following hypothesis of VC-innovation nexus (innovation to VC), FBH^e is feedback hypothesis of VC-innovation nexus, and NEH^e is neutrality hypothesis of VC-innovation nexus.

SLH^f is supply-leading hypothesis of innovation-financial development nexus (innovation to financial development), DFH^f is demand-following hypothesis of innovation-financial development nexus (financial development to innovation), FBH^f is feedback hypothesis of innovation-financial development nexus, and NEH^f is neutrality hypothesis of innovation-financial development nexus.

positive impact on per capita economic growth. This supports the recent findings of Fuss and Schweizer (2012), and Samila and Sorenson (2011), who follow similar approaches.

Secondly, we utilized generalized impulse response functions (GIRFs) to observe the effect of a one-off shock to one of the innovations on the current and future values of the endogenous variables (Pesaran and Shin, 1998; Koop et al., 1996). One advantage of using impulse response analysis in a vector autoregressive framework is that it allows for the treatment of responses to shocks, known as 'cross effects.' These GIRFs offer additional insights into how shocks to VC investment can affect and be affected by innovation, financial development, and per capita economic growth. Expressive GIRFs are considered an out-of-sample Granger causality test, and hence, the discussions on the long-run Granger causality could be applied in this part of the study as well. Since the shocks are both negative and positive events, the economic application for the planners is a rebalancing of their venture capital investment, innovation, financial development, and per capita economic growth. For instance, if a government introduces a sudden change to venture capital investment (for example, through tax reliefs or direct investment subsidies), then based on our empirical results, such a change would affect the economy in terms of innovation and ultimately the per capita economic growth.

The results from our FMOLS, DOLS, and GIRFs estimations are not reported here due to space constraint but are available from the authors upon request.

5. POLICY IMPLICATIONS AND CONCLUSION

This study analyses the possible simultaneous causal relationships between venture capital investment, innovation, financial development, and per capita economic growth. To study the dynamics between these variables, we use a panel Granger causality test. We find that the variables are cointegrated. Most importantly, there is clear evidence that

venture capital investment (early stage, later stage and total investments), innovation and financial development matter in the determination of long-run per capita economic growth. The empirical analysis also suggests that there are complex endogenous relationships between the four variables in the short run based on the different innovation indicators and venture capital investment measures that are used in the analysis. The results suggest that for long term economic growth in Europe, policy-makers must devise strategies to further develop their venture capital industry and their financial sector, as well as improving their countries' innovative capacity. Examples of such strategies include giving priority to venture capital investment, adopting appropriate revenue-neutral policies,[21] and ensuring that the venture capital ecosystem is robust and dynamic to nurture the next-generation of enterprises.

The financial ecosystem should have adequate access to financial resources and transparent governance systems to reduce asymmetric information on the growth prospects of firms. Here, the financial systems for the European economies should provide adequate venture capital funding for start-ups with diverse risk profiles. Start-up businesses in their early stage of development will require funding for R&D and other support to develop their technology and IP to be market-ready and competitive. These investments are critical for the ventures to transcend the 'valley of death', a period when the firms face periods of negative cash-flow, before their products can generate adequate revenues to sustain the enterprise.

On the other hand, more mature start-up businesses will require funding to expand their market reach for resources, talent and new markets. The funding should also be provided for these start-up businesses to enhance their product richness, which include

[21] An example of such initiative includes transferring public funds away from offering general subsidies, but providing support to start-up businesses and reducing capital gains taxes on venture capital firms (Keuschnigg, 2004).

enhancing and expanding their range of products, improving the quality of the products and building a global brand.

A recent study by Metzger (2016) shows that the start-up ecosystems in European countries are sluggish compared to their U.S. counterparts. The study highlights that the VC market in Europe is highly fragmented due to wide-ranging reasons, such as: diverse stages of development of the European economies; varying size of the economies; and different legal systems, regulatory architectures and innovation ecosystems. The study also highlights that the VC ecosystem in the U.S. is significantly larger and more sophisticated as compared to the VC ecosystems across Europe. The study concludes that the average annual VC investments from 2007 to 2015 in the U.S. was 0.211 per cent of GDP, while in Europe it was only 0.028 per cent of GDP.

The U.S. VC ecosystem is also strongly supported by the government and the private sector. In the latter case, a majority of the investors are experienced and successful entrepreneurs who primarily support later stage VC investments. There are also initiatives such as the Small Business Investment Companies (SBIC) program, where the government provides loans to privately-owned and managed investment funds that utilize the government-backed loans and private capital to support the development of small business ventures (U.S. Small Business Administration, 2017). The vibrant capital market in the U.S. also contributes to the success of many of the start-ups in the U.S. by providing them a channel to obtain funding for expansion via initial public offerings (IPOs). In 2015, 18 per cent of the start-ups in the U.S. exited via IPOs (Metzger, 2016).

Metzger and Lo (2016) compared VC financing in the US and Germany, the leading economy in Europe. The study found that on average the VC financing in the US was seven times higher than in Germany for the period from 2007 to 2015. During the same period, the U.S. allocated nine times more VC financing for seed funding and five times

more for the start-up phase than Germany. The former help US start-ups to undertake their proof-of-concept and proof-of-market faster than German start-ups. The latter assist US start-up businesses to move to the mature stage of development at a faster pace than German start-up businesses.

Metzger and Lo (2016) also showed that the U.S. provides seven times more VC investments for later stage development of start-up businesses than Germany. This has helped U.S. start-up businesses expand their global market presence and leadership much faster than their German counterparts. The differences in the competitiveness of the start-ups in these two countries are further evidenced by the number of start-ups that reach for IPOs. 115 start-up firms in the U.S. went public in 2015 compared to 21 in 2008. In Germany, the number of start-ups going public were 16 in 2015 compared to 2 in 2008 (Metzger and Lo, 2016).

The above discussion and evidence from other countries show that without a sound institutional setup and financial ecosystem that foster effective public-private partnerships, models to mobilise venture capital investment and other business support systems for start-up businesses with diverse risk profiles will not be able to sustain viable venture capital industries (Li and Zahra, 2012; Gazanol and Thornary, 2016; and Adey and van der Schans, 2016). This may hinder the development of start-up enterprises that have the potential to develop next generation technologies and innovations to contribute to economic growth.

The empirical results of the present study also show that long-term per capita economic growth is dependent on the ability of the economies of the selected European countries to move up on the innovation scale in order to remain globally competitive. This requires an efficient allocation of resources for R&D activities to propel the key economic sectors in the European countries. For R&D to contribute to economic development,

efforts to strengthen the national innovation ecosystem (NIS) are critical. In this context, public policies to continuously improve the NIS include: continuous development and upgrading of the nation's scientific and technological infrastructure; adequate resources to increase the quantity and quality of creative talent in the country; incentives to foster strong partnerships and linkages between all stakeholders in the economy; and adequate financial and other resources for R&D activities that will enhance process improvements and product development, all of which will contribute to economic development.

The results of this study also suggest that countries with strong economic growth tend to have national innovation and economic plans to move key sectors of the economy up the global innovation value chain in the form of the efficient generation of patents. The key strategies include providing support to foster translational research, where scientific publications and R&D work are converted into patents and other intellectual properties that are of value to industries.

Countries with high economic growth, especially the developed economies within the European Union, are at the forefront of developing a vibrant venture capital industry that assists research institutions and researchers with creation of start-up businesses to commercialise their patents (Samila and Sorensen, 2010; and Faria and Barbosa, 2014). The venture capital industry is also likely to support business development by providing: capability development programs, including mentoring and enhancing entrepreneurial acumen (Popov and Roosenboom, 2013); assistance in managing the intellectual property; creating new networking opportunities that have commercial value and strengthening the firm's internationalisation strategy (Scherteler and Tykova, 2011). These initiatives ensure that firms are able to create value for their investors and the broader economy.

In summary, the global economic landscape has undergone unprecedented changes over the last two decades due to rapid technological development and this change is expected to continue unabated. The empirical results from our study show that the creation of a vibrant venture capital industry to support early and late start-up businesses, a sound financial sector, and a strong national innovation ecosystem are important drivers for sustained economic growth in European countries and conceivably many other countries around the globe.

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Table A. 1: Studies on the Nexus between Economic Growth and Three Other Variables (Individually): Venture Capital Investment, Financial Development, and Innovation

Studies	Variables	Country	Time Period	Major Findings
Part A : Between Economic Growth and Venture Capital Investment				
Carvell et al. (2013)	C	USA	1960-2010	DFH[a]
Fuss and Schweizer (2012)	C	USA	1991-2006	DFH[a], NEH[a]
Gompers and Lerner (1998)	C	USA	1980-1993	DFH[a]
Pradhan et al. (2016b)	A, B, C	EEA countries	1989-2013	SLH[a], DFH[a], FBH[a], NEH[a]
Part B : Between Economic Growth and Financial Development				
Al-Yousif (2002)	D, E	30 developing countries	1970-1999	SLH[b], DFH[b], FBH[b], NEH[b]
Pradhan et al. (2014)	D, E	ASEAN countries	1961-2012	SLH[b], DFH[b], FBH[b], NEH[b]
Mukhopadhyay et al. (2011)	D, E	10 Asian countries	1961-2011	SLH[b], DFH[b], FBH[b], NEH[b]
Kar et al. (2011)	D	15 MENA countries	1980-2007	SLH[b], DFH[b],
Part C : Between Economic Growth and Innovation				
Agenor and Neanidis (2015)	F	38 countries	1981-2008	SLH[c]
Galindo and Mendez (2014)	F	13 developed countries	2002-2007	FBH[c]
Guloglu and Tekin (2012)	F, G	13 OECD countries	1991-2007	SLH[c]
Hasan and Tucci (2010)	G	58 countries	1980-2003	FBH[c]
Kirchhoff et al. (2012)	G	USA	1990-1989	SLH[c], DFH[c], FBH[c], NEH[c]
Pradhan et al. (2016a)	F, G	Eurozone countries	1960-2000	SLH[c], DFH[c], FBH[c], NEH[c]
Sadraoui et al. (2014)	F	32 countries	1970-2012	FBH[c]

Note 1: SLH[a]: Supply-leading hypothesis: unidirectional causality from venture capital investment to economic growth; DFH[a]: Demand-following hypothesis: unidirectional causality from economic growth to venture capital investment; FBH[a]: Feedback hypothesis: bidirectional causality between venture capital investment and economic growth; and NLH[a]: Neutrality hypothesis: no causality between venture capital investment and economic growth.

Note 2: SLH[b]: Supply-leading hypothesis: unidirectional causality from financial development to economic growth; DFH[b]: Demand-following hypothesis: unidirectional causality from economic growth to financial development; FBH[b]: Feedback hypothesis: bidirectional causality between financial development and economic growth; and NLH[b]: Neutrality hypothesis: no causality between financial development and economic growth.

Note 3: SLH[c]: Supply-leading hypothesis: unidirectional causality from innovation to economic growth; DFH[c]: Demand-following hypothesis: unidirectional causality from economic growth to innovation; FBH[c]: Feedback hypothesis: bidirectional causality between economic growth and innovation; and NLH[c]: Neutrality hypothesis: no causality between economic growth and innovation.

Note 4: A is venture capital at early stage investment, B is venture capital at later stage investment, C is total venture capital stage investment (both at early stage and later stage), D is banking sector development, E is stock market development, F is input-types of innovation, and G is output-types of innovation.

Note 5: OECD is organisation for economic cooperation and development, EEA is European Economic Area countries, ASEAN is Association of Southeast Asian Nations countries, and MENA is Middle East and North Africa countries.

Table B.1: Summary of PCA-related Information for our Innovation Index (CII)

Part A: Eigen Analysis of Correlation Matrix

PCs	Eigen Value	Proportion Variance	Cumulative
1	2.006	0.251	0.251
2	1.524	0.191	0.441
3	1.23	0.154	0.595
4	1.032	0.129	0.724
5	0.939	0.117	0.841
6	0.528	0.066	0.907
7	0.437	0.055	0.962
8	0.305	0.038	1

Part B: Eigen Vectors (component loadings)

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
PAR	0.418	0.157	0.278	-0.146	-0.573	-0.515	0.328	0.04
PAN	0.08	0.678	0.181	0.231	-0.136	0.07	-0.565	-0.324
RRD	0.193	-0.201	0.303	0.688	0.437	-0.375	0.09	-0.134
STJ	0.59	-0.107	-0.078	0.025	-0.019	0.564	0.29	-0.48
TRR	0.168	0.021	-0.799	-0.036	0.078	-0.468	-0.126	-0.3
TRN	0.247	0.602	-0.199	0.056	0.383	0.095	0.345	0.51
RDE	0.555	-0.316	-0.041	0.022	-0.063	0.072	-0.57	0.505
HTE	0.188	0.029	0.336	-0.668	0.553	-0.192	-0.147	-0.201

Note 1: PCs denotes principal components.

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

Table B.2: Summary of PCA-related Information for our Financial Development Index (FID)

Part A: Eigen Analysis of Correlation Matrix

PCs	Eigen Value	Proportion Variance	Cumulative
1	5.612	0.51	0.51
2	1.745	0.159	0.669
3	1.351	0.123	0.792
4	0.97	0.088	0.88
5	0.614	0.056	0.936
6	0.455	0.041	0.977
7	0.101	0.009	0.986
8	0.078	0.007	0.993
9	0.038	0.003	0.996
10	0.031	0.003	0.999
11	0.006	0.001	1

Part B: Eigen Vectors (component loadings)

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
CBA	0.174	-0.61	-0.344	0.031	-0.002	-0.2	-0.007	0.332	0.372	0.479	0.023
DBA	0.384	0.007	-0.285	-0.121	-0.074	-0.06	-0.018	0.65	0.069	-0.549	-0.135
DBT	0.213	0.591	0.286	-0.03	-0.011	0.058	-0.032	0.353	0.408	0.477	0.014
DCP	0.4	-0	-0.212	-0.079	-0.109	-0.138	-0.012	-0.053	-0.506	0.447	-0.547
LIQ	0.299	-0.02	-0.214	0.149	0.489	0.763	0.095	-0.104	0.018	0.015	-0.007
PCO	0.391	-0.01	-0.226	-0.066	-0.142	-0.199	-0.044	-0.567	0.613	-0.113	-0.142
PCM	0.4	0.012	-0.234	-0.09	-0.102	-0.139	0.034	-0.043	-0.238	0.168	0.812
MAC	0.274	-0.21	0.305	0.372	0.503	-0.351	-0.518	0.045	-0.016	-0.018	0.024
TRA	0.278	-0.32	0.473	-0.091	0.147	-0.148	0.736	0.034	0.045	-0.01	-0.027
TUR	0.16	-0.33	0.403	-0.6	-0.216	0.347	-0.42	-0.024	-0.007	0.001	0.022
LDC	0.191	-0.16	0.206	0.66	-0.625	0.258	-0.016	0.032	-0.014	-0.03	0.01

Note 1: PCs denote principal components.

Note 2: CBA is central bank assets, DBA is deposit money bank's assets, DBT is deposit money bank assets and central bank assets, DCP is domestic credit to private sector, LIQ is liquidity liabilities, PCO is private credit by deposit money banks and other financial institutions, PCM is private credit deposit money banks, MAC is stock market capitalization, TRA is traded stocks, TUR is turnover, and LDC is listed domestic companies.

Table C.1: Definition of Variables

Notation	Definition
PEG	**Per capita economic growth:** percentage change in per capita gross domestic product (GDP).
VCE	**Venture capital at early stage investment:** level of investment performed by venture capital firms towards young businesses in their primary development stage, as a percentage of GDP.
VCL	**Venture capital at later stage investment:** level of investment performed by venture capital firms towards young businesses in need of expansion capital, as a percentage of GDP.
VCT	**Total venture capital:** venture capital investment at both early stage and later stage, as a percentage of GDP.
FID	**Composite index of financial development:** based on CBA, DBA, DBT, DCP, LIQ, PCO, PCM, MAC, TRA, TUR, and LDC.
CBA	**Central bank assets:** expressed as a percentage of GDP.
DBA	**Deposit money bank assets:** expressed as a percentage of GDP.
DBT	**Deposit money bank assets to money bank assets and central bank assets**: expressed in percentage.
DCP	**Domestic credit to private sector**: expressed as a percentage of GDP.
LIQ	**Liquid liabilities:** liquid liabilities to GDP, expressed in percentage.
PCO	**Private credit by deposit money banks and other financial institutions**: expressed as a percentage of GDP.
PCM	**Private credit deposit money banks**: expressed as a percentage of GDP.
MAC	**Stock market capitalization:** total value of all listed shares in a stock market as a percentage of GDP.
TRA	**Traded stocks:** total value of all traded stocks in a stock market exchange as a percentage of GDP.
TUR	**Turnover:** total value of shares traded during the period divided by the average market capitalization for the period.
LDC	**Number of listed companies:** number of domestically incorporated companies listed on the country's stock exchanges at the end of the year per million population.
CII	**Composite index of innovation:** based on PAR, PAN, RRD, STJ, TRR, TRN, RDE, and HTE.
PAR	**Patents filed by residents:** in numbers per thousand population.
PAN	**Patents filed by non-residents:** in numbers per thousand population.
RRD	**Researchers in research and development activities** in numbers per thousand population.
STJ	**Scientific and technical journal articles**: in numbers per thousand population.
TRR	**Trademark applications by residents**: in numbers per thousand population.
TRN	**Trademark applications by non-residents**: in numbers per thousand population.
RDE	**Research and development expenditure**: as a percentage of GDP.
HTE	**High-technology exports:** as a percentage of GDP.

Note 1: Variables above are defined in the World Bank's *World Development Indicators* and the European Venture Capital Association's *Venture Capital Database*.

Note 2: All monetary values are measured in *real* 2000 US dollars.

Table D.1: Descriptive Statistics for the Variables

Var	PEG	VCE	VCL	VCT
Part 1: Summary Statistics				
Mea	1.22	-2.17	-1.89	-1.54
Med	1.23	-1.89	-1.59	-1.4
Max	1.44	-0.79	-0.49	-0.34
Min	0.8	-8.34	-7.83	-5.71
Sta	0.08	1.14	1.24	0.79
Ske	-1.13	-3	-3.03	-2.24
Kur	6.65	13.1	13.1	9.56
JB	201.6	152.1	151.4	692.4
Part 2: Correlation Matrix				
PEG	1			
VCE	0.14*	1		
VCL	0.13*	0.89***	1	
VCT	0.20**	0.91***	0.96***	1
FID	0.19**	0.18**	0.15*	0.16*
PAR	0.13*	0.39***	0.29***	0.33***
PAN	0.10*	0.37***	0.35***	0.38***
RRD	0.10*	0.03	0.16*	0.10*
STJ	0.41***	0.33***	0.12*	0.17**
TRR	0.13*	0.10*	0.10*	0.40***
TRN	0.21***	0.10*	0.01	0.10*
RDE	0.31***	0.47***	0.29***	0.36***
HTE	0.11*	0.17**	0.16**	0.14**
CII	0.27***	0.41***	0.22**	0.30***

Note 1: PEG is per capita economic growth, VCE is venture capital at early stage investment, VCL is venture capital at later stage investme is trademark applications- residents, TRN is trademark applications- non-residents, RDE is the research and development expenditure, HTE

Note 2: Var denotes variable, Mea is mean, Med is median, Max is maximum, Min is minimum, Sta is standard deviation, Ske is skewness,

Note 3: *****,** ** and * indicate that the parameter estimates are significant at the 1%, 5% and 10% levels, respectively.

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