

## Public Expenditure in Research and Development and Venture Capital Commitments

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*This study investigates the relationship between Public Expenditure on Research and Development (PR&D) Venture Capital (VC) Investment. Using a comprehensive database of 40 countries: the OECD country-members plus Argentina, China, Romania, Russian Federation, Singapore and South Africa, from 1998 to 2012, we find that PR&D has a positive effect on VC Investment. PR&D can affect some factors that could increase or reduce the expected rate of return for VC investments, but our outcomes indicate a net effect positive and PR&D does seem to generate value through fostering VC activity in the economy. This is especially true in countries with higher institutional quality and higher level of articles published by the scientific community. This could indicate two things: first, that PR&D is more efficient and strategically addressed in countries with high institutional quality; and second, it confirms that scientific production works in partnership with PR&D in generating VC opportunities. PR&D is more important for the generation of VC investments in countries with lower infrastructure; in these countries, the government decision for increasing PR&D takes more relevance in fostering active VC markets. The above conclusions are confirmed for early stage (ES), high technology (HT) and manufacturing sector (MS) venture capital investments, indicating that PR&D is specifically important for these three kinds of VC investments, however infrastructure availability remains definitive to increase MS venture capital investments. The results are based on a panel study controlling endogeneity with a generalized method of moments (GMM) dynamic panel estimator model with a collapsed instrument matrix and two lags.*

Keywords: *Venture Capital, Public Expenditure in R&D, Institutional quality, High Technology Investments, Start-up.*

### Introduction

There is consensus in the literature about the importance of venture capital (VC) funds financing for new business creation (Black & Gilson, 1998; Hellmann & Puri, 2000, 2002; Kortum & Lerner, 2000, Popov & Roosenboom, 2013). Companies in early development stages and inside of high-tech industry sectors take advantage from VC funds investments, because they offer market knowledge, managerial guidance and greater risk tolerance (Gompers, 1995; Gabriellsson & Huse, 2002; Hsu, 2004).

Recently a stream of research has been devoted to guide policy makers on taking special measures to promote VC market development (Jeng & Wells, 2000; Belke *et al.*, 2002; Megginson, 2004). However, a few studies have focused on the relation between Public Expenditure on Research and Development (PR&D) and the creation of active VC markets. As economies become ever more dependent on innovation and creation of new sources for achieving sustained growth (like the produced by VC investments), PR&D has received a high priority in the economic policy agenda and has been absorbing large sums of public money, but we still know little about the benefits of PR&D in the creation of active VC markets. This paper contributes to fill that gap by providing a comprehensive study of the effect of PR&D on VC commitments.

Previous studies have found that R&D expenditures are positively related to VC investments regardless of their sources (Gompers *et al.*, 1998 for United States over 1976–1994; Mondher & Kaouthar, 2011 for 21 European countries over 1997–2006; Romain & de La Potterie, 2004

for 16 OECD Countries between 1990 and 2000; Adongo, 2011 for 37 European countries) while others have not found a significant relation between the total R&D expenditure (Felix *et al.*, 2007, for 23 European countries from 1992 to 2003) or Public R&D expenditure (Da Rin *et al.*, 2006 for 14 European countries between 1988 and 2001) and the VC activity.

Our focus is oriented specifically to shedding light on the effect of PR&D in generating VC activity and determining what economic conditions could affect the productivity of the possible benefits of PR&D on VC markets. We explore how this relation is affected when PR&D interacts with three relevant country-level factors that can make an environment more fertile for VC investment: institutional quality degree, scientific production level and infrastructure availability.

For this purpose we use a panel data with a larger country sample and a bigger time period (40 countries: the OECD country-members plus Argentina, China, Romania, Russian Federation, Singapore and South Africa, from 1998 to 2012). Insofar, some researchers have identified a possible mutual interdependence of public and private R&D expenditures that could affect the relation between PR&D and VC investments (Kortum & Lerner, 2000; Becker, 2014; David *et al.*, 2000), we advance introducing a difference and system GMM dynamic panel estimator model with a collapsed instrument matrix and two lags to control for endogeneity problems, obtaining more robust conclusions.

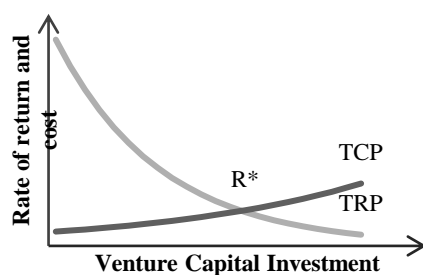
## The Relation Between Public Investment on R&D (PR&D) and Venture Capital Commitments

The influence of PR&D over VC industry can be analyzed using an adaptation of a familiar, rather elementary aggregate equilibrium model of fund-level investment behavior. At one point in time, an array of potential VC projects are available to invest in the market, VC funds in the market consider the expected cost and benefit streams for available projects and calculate its expected rate of return (ERR). VC funds use these rates of return to rank the associated projects in descending order of forecasted yield and forming a total return profile (TRP) to build a VC portfolio.

TRP has a downward sloping in relation with VC investment amount and cross with the total cost profile (TCP) at break-even point of equilibrium ( $R^*$ ). In Figure 1, TRP and TCP are plotted on the vertical axis; while the horizontal axis represents the cumulated amount of investment required as one proceeds down the list of VC investment opportunities available in the market (demand for VC investments).

The TCP reflects the minimum average rate of return required to cover expenses related with fund administration and the rate of return expected by the fund investors. The last one reflects the investor's opportunity cost in relation with their risk appetite. Although the assumption of risk neutrality on the part of the fund is implied by the use of the ERR, the upward slope of TCP schedule over its full range reflects that VC resources are limited and as volume of VC investment is increased, the fund will require finance projects attracting recourses from external financing and this would tend to push its TCP upwards.

In the next paragraphs, we use this framework to discuss how PR&D could increase and decrease TRP or TCP associated to VC aggregate fund portfolio and how it could affect funds decision to increase or reduce its investment commitments.



**Figure 1.** Relation between Total Return Profile (TRP) and Total Cost Profile (TCP) for Venture Capital Funds

### *PR&D and Increasing VC Investment Opportunities Return*

Existing literature about VC activity determinants mention that PR&D policy could lead to either an increase in the returns associated to TRP or a reduction on costs associated to TCP in several ways. PR&D can raise innovative output and expand scientific knowledge base. Schumpeter (1934) and Ames (1961) have mention that

PR&D, through formalizing and making public advancements in different research fields, can lead to the generation of new valuable entrepreneurial ideas and marketable new products and processes, increasing the demand for VC investments.

As is known, one of the rationales for PR&D is the correction of the market failures in the production of scientific and technological knowledge, arising from the "incomplete private appropriability" problems identified by Nelson (1959) and Arrow (1962). In response to the tendency towards under provision of knowledge-based innovative effort on the part of private sector, governments have opted for the direct procurement or production in public facilities, for example financing public research institutes and national laboratories.

Where public funds are intended for test facilities construction, durable research equipment acquisition and specialized research teams assembly, related VC investment opportunities can emerge at lower operational costs, and thereby it could derive in higher expected internal rates of return (Leyden & Link, 1991; David *et al.*, 1992).

Public funding of R&D can contribute indirectly, by generating knowledge spillovers and by complementing and stimulating private R&D expenditures. For example, the defense and pharmaceutical related research expenditures funded through public agencies may create social benefits in the form of knowledge and training spillovers. These spillovers emerge like opportunities to boost private sector productivity and encourage investments by VC funds interested in exploiting the technological innovations related, from which will flow future streams of cash flows (Jaffe, 1989; Adams, 1990; Acs *et al.*, 1991; and, Toole, 2007).

The knowledge spillover from PR&D could reduce not only the costs associated to VC investment opportunities, but decrease the project costs variance and, simultaneously the risk perceived by VC funds. Additionally, these knowledge spillovers could encourage the "Horse Race" for proprietary inventions in the field (Cohen & Levinthal, 1989), and this represents an incentive for VC funds to invest in projects related in order to take advantage of opportunities to increase its ERR.

Government contract R&D could be a signal of future public sector product demand, as well as, future private sector demand in markets for dual-use goods and services. Venture Capitalists attentive to these signals could catch projects targeted to those markets. Similarly, Public R&D in a particular area may signal government intention to promote the use of a particular technology and this may entail either a future commitment to diffusion activities by public agencies, or favorable tax incentives for adoption of such technologies. Consequently the expected rate of return on VC financed projects in these fields would be raised.

### *PR&D and Decreasing VC Investment Opportunities Return*

On the other hand, there is not few the academics who arrive to contrary conclusions: they found that some public R&D efforts have failed to provide significant commercial spillovers because inefficiency in the selection of government agencies and corruption generate a

misallocation of resources on low-impact projects (Cohen & Noll, 1991). In this case no significant effect would have PR&D in generating VC opportunities.

An additional argument against benefits of PR&D over the returns of VC industry is that direct funding of R&D programs designated by government agencies prioritizes projects that are perceived to offer high marginal social rates of return. Such funding could be concentrated in areas where there is a large gap between the social and the private rate of return. In these cases, resulting ERR could be no attractive to VC funds because they need to ensure a minimum return to cover expenses related with fund administration and the rate expected by the fund investors.

Sometimes, publicly funded research and development are earmarked by governments to the public domain. This could produce a crowding out effect over venture capitalist initiative (mainly in the high technology seed VC investments) in two senses: the first one, is that venture capitalist couldn't enjoy the exclusive returns related with patents because property rights would be publicly held. The second one, is a displacement effect, Venture Capitalists might be discouraged from undertaking some investments because they wouldn't want to compete with the government agencies. They would wait for outcomes of the governmental initiative because they know about state incentives to disseminate these outcomes. The resulting alteration push the shape of the TRP schedule downward and to the left, specifically for technological seed VC investments.

The competition between the public and private sectors for specialized resources like human talent and facilities, can rise the prices of inputs used in technological VC investment opportunities, translating into higher costs for VC projects and reducing its ERR. Since technological VC projects require specialized inputs, in some countries the supply of, say researchers and engineers with particular expertise, can be low. The short-run impact of public R&D demand of this kind of inputs increases its costs and consequently, reduces the expected rate of return on the private sector's investment, leading some VC projects to be curtailed – *ceteris paribus*.

A last consideration in this sense could be that, where PR&D sends a signal of future public or private sector product demand in markets for dual-use goods or services and attracting Venture Capital investment (as was mention above), the resulting payoffs structure would induce wastefully duplicative private investments and be associated with excessive expenditures directed toward hastening the projects completion. The consequence could be not only a reduction in project rates of return; also these phenomena could generate overfunded sectors, whereas others are underfunded.

As it can be concluded, the question about could private investment be crowded out by public investment in technological fields has been viewed in the larger context of the political economy literature. Many researchers have taken a critical position regarding the State intervention in the economy. As we mentioned the rationale for PR&D starts on the presupposition that too little research would be performed by private sector initiative, but intense concern surrounds the possibility that public allocations are substitutes of investments that private firms would otherwise undertake. There is a worry that the use of

taxpayers 'money has rendered far less effectual than might be supposed in augmenting society's investment in generating technological progress (Bergstrom *et al.*, 1986; David, 1997).

Literature reviewed above allows us to identify a persisting lack of a clear-cut consensus about if PR&D encourage or displace the related private investment. Empirical works also show contradictory findings, for example, Robson (1993) concludes that there is a one-for-one stimulus, Wallsten (1999) concludes that there is a one-for-one crowding-out, whereas Da Rin *et al.* (2006) find no evidence of an effect of increased public R&D spending on the VC activity, specifically for high technology and early stage VC investments.

We have a considerable doubt about the idea that there is a universal relationship of a determined type, we think that this relation can be affected by other variables surrounding in the economy. Specifically, besides testing significance and direction of relation between PR&D and VC, we are seeking to explore how this relation is affected when PR&D interacts with three relevant country-level factors that can make an environment more fertile for VC investment: institutional quality degree, scientific production level and infrastructure availability.

## Data and Variables Description

Information about venture capital investment comes from Thomson ONE, private equity database (venture capital module). The Thomson ONE database contains information for venture capital deals performed in 40 countries studied: the OECD country-members plus Argentina, China, Romania, Russian Federation, Singapore and South Africa, over a 14 year period, from 1998 to 2012.

The dependent variable (Venture capital activity) is measured in terms of three proxies. The venture capital investment (*vc\_inv*) indicates the total venture capital investment made at year *i* by country *j*. It is estimated as the natural log of one plus venture capital investment to economically active population ratio (18–64 years old) in each country-year (Popov & Roosenboom, 2013; Bottazzi & Da Rin, 2002; Da Rin *et al.*, 2006; Kortum & Lerner, 2000; Herrera-Echeverri *et al.*, 2014). Second proxy is venture capital deals (*vc\_deal*), which denotes the number of venture capital investment deals in each country-year. It is computed as the natural log of one plus venture capital deals to economically active population ratio (18-64 years old) (Cumming & Li, 2013; Sahaym *et al.*, 2010). Finally, to check the conclusions robustness we use a probit model where total number of VC deals at year *i* by country *j* is the independent variable.

To meet other study concerns, venture capital activity is calculated using three additional investments criteria: company development stage, company technological level and company economic sector. For the first criteria, the Thomson One's Private Equity/Venture Capital database classifies investments in the following categories: seed, start-up, expansion, replacement capital, and buyouts. VC investments are defined as the sum of the first four categories. Early stages VC investments are the sum of the first two categories.

The second criterion identifies VC investments in high-tech companies and it includes the following sectors: communications, computing and related, biotechnology and related, electronics, medicine and related. The third criterion identifies the VC investments in companies of the manufacturing sector, defined as the sum of investments in the 31, 32 y 33 business sector NAIC codes.

The explanatory variable is proxy with “Ps\_r+d” that measure Public expenditure on research and development (PR&D) at year  $i$  by country  $j$  as share of Gross Domestic Product (GDP). PR&D represents public resources destined to activities undertaking for discovering or developing new products, including the improving of versions and qualities of the existing ones and the discover or the development the new or more efficient processes of production (SNA<sup>1</sup>, 1993). The data is in local currency, for this research purposes was calculated as a share of GDP. We work with annual flows of PR&D because this reduces positive serial correlation between dependent and independent variables<sup>2</sup>.

Six control variables are included to ensure that the relation between explanatory variables and dependent variable can be authenticated. The first control variable is “Inst\_qual”: quality of institutions determined according to the most recent version of “Worldwide Governance Indicators (WGI)” (Kaufmann, Kraay, & Mastruzzi, 2010).

Second control variable is the market capitalization “Mar\_cap” is the share price multiplied by the number of issued shares of domestic companies listed in the stock market in the previous year; investment companies, mutual funds or other forms of collective investment are not included. A higher stock market capitalization is preferred for venture capital investments (Black & Gilson 1998; Gompers, 1995; Jeng & Wells, 2000; Megginson 2004; Nahata, 2008; Schertler & Tykvova, 2012).

The third control variable proxies the innovation level of the country. “Art\_pub” denotes the science & engineering articles published coming from country. To take into account the economic environment, we use the volume of imports and exports, “Trade” and GDP per capita. We use two variables to proxy the infrastructure development level of a country in a year: the Public expenditure in gross fixed capital formation (Public\_fbk) as percentage of GDP and, the total road network reported in thousands of kilometers, which includes motorways, highways and other national or regional roads in a country (Road).

By convention in the SNA 1993, all the outputs produced by research and development, staff training, market research and similar activities are treated like being consumed as intermediate inputs even though some of them may bring future benefits. Intermediate consumption measures the value of goods and services that are transformed or entirely used up in the course of production during the accounting period. It does not cover the costs of using fixed assets nor expenditures on the acquisition of fixed assets. Therefore, no collinearity between Public\_fbk and Ps\_r+d is assumed.

## Empirical Methodology

The aim of this research is to measure how PR&D influences the venture capital commitments in sample countries and extend that analysis to assess the effects of PR&D over three specific kinds of VC investments: early stage, high technology and manufacturing sector. For this propose, we use the panel data technique, where the main unit of observation is the VC investment in a country-year:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 Z_{it} + \beta_3 D_i + \beta_4 D_j + \varepsilon_{it} \quad (1)$$

Equation (1) describes the model. Where  $Y_{it}$  denotes the VC investment (sensitivity issues are established for total, early stage, high technology and manufacturing VC investment).  $X_{it}$  and  $Z_{it}$  indicates the associated variables to PR&D and control variables respectively to each country in a year.  $D_i$  is a matrix of year dummies to control VC industry effects, which is common to all countries.  $D_j$  is a matrix of dummies to control country effects, taking into account the convergence phenomena (Barro & Sala-i-Martin, 1992). Finally,  $\varepsilon_{it}$  is the idiosyncratic error.

We find temporal effects significance. Hausman Specification Test indicates fixed effects. Pesaran CD (cross-sectional dependence) Test was used to detect correlation of residuals across entities. Modified Wald Test and Wooldridge Test are used to detect heteroskedasticity and autocorrelation respectively. Panel Corrected Standard Errors, PCSE (Beck & Katz, 1995) estimators are used to solve contemporaneous correlation, autocorrelation and heteroskedasticity problems. With an appropriate period of time in the sample (14 years), it is possible to use the correction through PCSE models (Beck, 2001).

## Analysis of Results

### *Public Expenditure on R&D and Venture Capital Commitments*

Table 1, column (1) shows the estimates from the basic panel data regression. The Dependent variable is the natural logarithm of VC investment scaled by economically active population (vc\_inv) and the main explanatory variable is Public expenditure on R&D (Ps\_r+d) as share of GDP. The coefficient is significant and positive, implying that the VC is higher in countries with higher PR&D. The numerical interpretation of regression coefficient is: increasing PR&D in a 1 % of GDP would increase the VC on average 36,620.7 dollars per inhabitant economically active. This simple first empirical test confirms the complementarity between private VC investment and public R&D investment.

Because PR&D can take more than a year to show results in Model (2), an alternative PR&D measure is used, the 3-year average of public expenditure on R&D (Ps\_r+d\_3 year). In this case the resulting coefficient is again positive and significant and its magnitude implies that on average VC investment level is higher in countries with greater PR&D. However, before addressing endogeneity concerns the above results should be seen with caution.

In table 1, models (1) using PR&D and (2) using 3-year average PR&D, show a positive and significant coefficient

<sup>1</sup> The System of National Accounts (SNA) available on <http://unstats.un.org/unsd/nationalaccount/sna2008.asp>

<sup>2</sup> That could happen when the stocks of PR&D are used in the regression models.

between VC investment and PR&D. This relation is tested once again in models (3) and (4) using PR&D and in model (5) and (6) using 3-year average PR&D but this time control variables are included in the models. All control variables show the behavior predicted in the literature (Lagged Inst\_qual, Mar\_cap, Art\_pub, GDP and Road show a positive and significant coefficient in relation with VC at 1 % or/and 5 %) and the relation between PR&D and 3-year average PR&D with VC investment follows positive and statistically significant. Results persist after controlling country specific developments that vary over time.

Table 1

VC Investment and PR&D

Independent variables	VC investment (vc_inv)					
	(1)	(2)	(3)	(4)	(5)	(6)
Lagged vc_inv						
Ps_r+d	366,2 (54.9)***		167,1 (50.3)***	128,9 (60.1)**		
Ps_r+d_3 year		409,6 (59.1)***			185,95 (56.7)***	174,23 (67.5)**
Inst_qual			0,55 (0.15)***	0,63 (0.23)***	0,56 (0.16)***	0,54 (0.23)**
Mar_cap			0,004 (0.00)**	0,007 (0.00)***	0,003 (0.00)**	0,004 (0.00)**
Art_pub			0,014 (0.00)***		0,015 (0.00)***	
Trade			0,003 (0.001)*	0,001 (0.001)	0,003 (0.002)	0,003 (0.002)
GDP			0,02 (0.006)***	0,03 (0.01)***	0,026 (0.01)***	0,032 (0.01)***
Road				0,39 (0.06)***		0,47 (0.06)***
Constant	1,58 (0.4)***	2,22 (0.4)***	0,23 (0.26)	0,25 (0.25)	0,12 (0.27)	-0,02 (0.29)
Time dummies	yes	yes	yes	yes	yes	yes
R <sup>2</sup>	0,40	0,35	0,53	0,53	0,48	0,45
Observations	422	422	385	336	390	353
Countries	36	36	36	35	37	39
Model	PCSE ar(1), het					

To advance in testing the positive relation between VC and PR&D, another robustness check is made using another proxy for VC. The natural logarithm of the number of VC deals scaled by economically active population (vc\_deal) is included to confirm the outcomes obtained to this point. Table 2, columns (1) to (6) show again that PR&D and 3-year average PR&D remain positive and significant both at 1 % or/and 5 % level in all models, including the models (10) to (13) where control variables were incorporated (note that control variables maintain the behavior presented in equations (3) to (6)). The conclusion is PR&D and 3-year average PR&D have a positive and significant relationship in increasing both the amount of investments and the number of VC deals.

Finally, a different specification was included in table 3 to check the robustness of above conclusions. In columns (2) and (3), total VC deals in a country-year is used as a dependent variable to regress with PR&D and 3-year PR&D. Taking into account the discrete nature of the number of VC deals, the initial specification is replaced with a Probit model. The coefficients of the explanatory variables do not change and they are significant at 5 % in the case of the lagged PR&D and at 10 % in the case of 3-year average PR&D.

### Endogeneity and Selection

The empirical methodology followed to this point may be exposed to endogeneity problems. Positives coefficients in the models do not imply necessarily causality between PR&D and VC. Becker (2014) mentioned that private and public R&D investment respond together to expectations of future technological shocks. This may result in endogeneity bias because governments and VC funds can guide their investment efforts in the same line of action. In general, strict exogeneity would imply that technological shocks do not affect simultaneously current PR&D, and VC. Obviously this assumption is difficult to hold, and this implies a possible endogenous relationship between VC and PR&D.

Table 2

VC Deals and PR&D

Independent variables	VC deals (vc_deal)					
	(1)	(2)	(3)	(4)	(5)	(6)
Lagged vc_inv						
Ps_r+d	165,9 (41.5)***		120,5 (38.6)**	113,5 (43.0)**		
Ps_r+d_3 year		287,8 (48.3)***			191,6 (41.2)***	189,7 (43.8)***
Inst_qual			0,55 (0.14)***	0,61 (0.21)***	0,65 (0.15)***	0,65 (0.24)***
Mar_cap			0,001 (0.001)	0,003 (0.001)**	0,001 (0.001)	0,001 (0.001)
Art_pub			0,007 (0.002)***		0,006 (0.002)***	
Trade			0,002 (0.001)*	0,001 (0.001)	0,002 (0.001)	0,002 (0.001)*
GDP			0,012 (0.005)***	0,013 (0.007)**	0,003 (0.006)	0,008 (0.007)
Road				0,23 (0.46)***		0,23 (0.05)***
Constant	1,22 (0.27)***	1,29 (0.29)***	0,23 (0.19)	0,19 (0.19)	0,13 (0.18)	-0,04 (0.17)
Time dummies	yes	yes	yes	yes	yes	yes
R <sup>2</sup>	0,48	0,44	0,56	0,57	0,54	0,55
Observations	422	422	386	337	392	355
Countries	36	36	36	35	37	39
Model	PCSE ar(1), het					

Likewise, the analysis of complementary and substitutes effects of public R&D over private investment in David *et al* (2000) mentions the possible mutual interdependence between public and private R&D expenditures. Omitted variables in the aggregate models can affect simultaneously VC and PR&D and be correlated with both, the public and the private R&D investment decisions.

One simple way to account for the possible endogeneity of current VC and PR&D is to use lagged values of PR&D. All the models in this work used lagged valued for independent and control variables. Lagged PR&D should be less correlated with current VC and hence should partially address the concern that VC investors and governments react the same way to current technology opportunities. A similar argument can be wielded to deal with the correlation that can emerge because the omitted variables in the aggregated models.

However, lagged PR&D variables are not a perfect solution to the endogeneity problem since VC investment opportunities and PR&D dynamics are likely to be correlated along longer periods. To address the econometric challenge

that this fact represents and obtain unbiased estimators in the models, we use difference and system GMM dynamic panel estimator model with a collapsed instrument matrix and two lags<sup>3</sup> (Roodman, 2009).

In table 3, the estimates from the 2SLS procedure are reported in column (1) where VC is regressed against the lagged PR&D (Ps\_r+d) and the lagged VC (Lagged vc\_inv). In both cases, the sign is positive and the effect is significant at the 10 % and 5 % statistical level, implying that the relevance condition is satisfied and the relationship between public R&D and VC continues strong after taking in account possible endogenous issues. In the same way that previous models tested in this paper, the behavior of all control variables after 2SLS procedure remains consistent. The p-value associated to the Hansen J-test required for the difference and system GMM dynamic panel estimator model, reject the null hypothesis indicating the validity of the instruments and the over-identifying restriction condition fulfillment. The robustness of above results is confirmed by Diff-in-Hansen test (excluding group and difference).

Table 3

**VC and PR&D Robustness**

Independent variables	Second Stage	Total VC deals	
	vc_inv (7)	(14)	(15)
Lagged vc_inv	0,22 (0.11)**		
Ps_r+d	262,8 (262.8)*	149,35 (75.48)**	
Ps_r+d_3 year			136,82 (83.61)*
Inst_qual	0,52 (0.24)**		
Mar_cap	0,004 (0.002)		
Art_pub	0,008 (0.004)**		
GDP	0,017 (0.014)		
Constant		1,28 (0.39)***	1,49 (0.47)***
Time dummies	yes	No	No
Observations	400	422	422
Countries	39	36	36
Model	2SLS_GMM	Probit	

**Sensibility to Country Environment Characteristics**

In following tables we analyze the country characteristics of the business environment that, in theory, can affects the productivity of PR&D to generate VC investment. We interact PR&D with four relevant country-level variables that can make a country more fertile for VC investment: Institutional quality (inst\_qual), the science & engineering articles published coming from the country (art\_pub), the Public expenditure in gross fixed capital formation (Public\_fbk) as share of GDP and the total road network reported in a country (Road).

In Table 4, column (1), PR&D interacts with institutional quality for countries with high (Ps\_r+d\*Inst\_qual\_high) and low (Ps\_r+d\*Inst\_qual\_low)

institutional quality (above or below the media, respectively). Coefficients magnitude shows that the effect of PR&D is greater in countries with higher institutional quality. Column (2) shows the same result using the interaction between PR&D with low and high institutional quality, both calculated with a three-year average (Ps\_r+d\_3 year\* Inst\_qual\_low\_3 year and Ps\_r+d\_3 year\* Inst\_qual\_high\_3 year, respectively). The magnitude of the resulting coefficients confirms that PR&D is more productive in countries with high institutional quality.

Table 4

**Sensibility to Inst\_qual and Art\_pub**

Independent Variables	Dependent Variable: VC investment			
	(1)	(2)	(3)	(4)
Ps_r+d*	149.45			
Inst_qual_low	(60.44)**			
Ps_r+d*	177.16			
Inst_qual_high	(55.24)***			
Ps_r+d_3 year*		118.98		
Inst_qual_low_3 year		(40.24)***		
Ps_r+d_3 year*		138.48		
Inst_qual_high_3 year		(41.01)***		
Ps_r+d*			68.44	
Art_pub_low			(46.25)	
Ps_r+d*			160.40	
Art_pub_high			(38.50)***	
Ps_r+d_3 year*				95.46
Art_pub_low_3 year				(41.37)**
Ps_r+d_3 year*				166.46
Art_pub_high_3 year				(38.00)***
Inst_qual	0,55 (0.19)***	0,61 (0.17)***	0,617 (0.15)***	0,68 (0.16)***
Mar_cap	0,005 (0.002)***	0,001 (0.001)	0,002 (0.001)**	0,001 (0.001)
Art_pub	0,013 (0.002)***	0,007 (0.002)***	0,004 (0.002)**	0,004 (0.002)**
Trade	0,003 (0.002)	0,002 (0.0013)	0,003 (0.001)**	0,002 (0.001)*
GDP	0,024 (0.007)	0,006 (0.005)	13,00 (0.005)**	0,007 (0.005)
Constant	0,379 (0.306)	0,447 (0.211)**	0,18 (0.198)	0,299 (0.191)
Time dummies	yes	yes	yes	yes
R <sup>2</sup>	0,404	0,586	0,522	0,599
Observations	422	339	422	339
Countries	36	36	36	36
Model	PCSE ar(1), het			

In this case, PR&D is complementary to institutional quality, implying that the benefits of PR&D on new VC investment generation improve when the levels of institutional quality are higher. This could indicate that the PR&D is more efficient and strategically addressed in countries with high institutional quality.

Countries with low institutional quality can report high levels of PR&D but the final destination of these resources can be affected by political compromises or other phenomena of this type that could reduce the positive effect if the PR&D resources are not well localized (Herrera *et al.*, 2014).

Another explanation for this effect could be that high institutional quality provides a stronger protection of intellectual property rights ensures a higher return to

<sup>3</sup> GMM estimators are accomplish by xtabond2 package in Stata (further information see Roodman, 2009)

investment. In countries with lower levels of institutional quality, the protection of venture capitalists may be deterred by the fact that the system will not protect innovative products adequately (Antonelli & Teubal, 2008).

In column (3), PR&D interacts with articles published. Countries with high ( $Ps_{r+d} * Art_{pub\_high}$ ) and low ( $Ps_{r+d} * Art_{pub\_low}$ ) level of articles published (above or below the media, respectively). Coefficients show that the effect of PR&D is greater in countries with higher level of articles published.

Table 5

**Sensibility to Roads Paved and FBK**

Independent Variables	Dependent Variable: VC investment			
	(5)	(6)	(7)	(8)
$Ps_{r+d}*$	143.75			
Road_low	(52.74)***			
$Ps_{r+d}*$	130.77			
Road_high	( 43.46)***			
$Ps_{r+d}*$	202.11			
Road_low_3 year	(50.6048)***			
$Ps_{r+d}*$	148.77			
Road_high_3 year	(44.63)***			
$Ps_{r+d}*$		227.79		
Public_fbk_low		(43.64)***		
$Ps_{r+d}*$		219.01		
Public_fbk_high		( 44.26)***		
$Ps_{r+d}*$			265.29	
Public_fbk_low_3 year			( 49.37)***	
$Ps_{r+d}*$			237.16	
Public_fbk_high_3 year			(49.82)***	
Inst_qual	0.57	0.63	0.40	0.46
	(0.21)***	(0.20)***	(0.17)**	(0.173)***
Mar_cap	0.003	0.002	0.003	0.001
	(0.001)**	(0.001)	(0.0011)***	(0.001)
Art_pub	0.007	0.008	0.005	0.0043
	(0.002)***	(0.002)***	(0.0017)***	(0.002)**
Trade	0.002	0.001	0.0038	0.002
	(0.001)	(0.001)	(0.0019)**	(0.0023)
GDP	0.01	0.0001	0.0073	0.001
	(0.007)	(0.006)	(0.0054)	(0.006)
Constant	0.10	0.289	-0.207	0.101
	(0.20)	(0.215)	(0.283)	(0.318)
Time dummies	No	yes	No	yes
R <sup>2</sup>	0,516	0,506	0,545	0,514
Observations	347	388	334	356
Countries	38	37	35	33
Model	PCSE ar(1), het			

For robustness, we test again the result using the interaction between 3-year average PR&D with low and high level of 3-year average articles published ( $Ps_{r+d\_3\ year} * Art_{pub\_low\_3\ year}$  and  $Ps_{r+d\_3\ year} * Art_{pub\_high\_3\ year}$  in column 4). Once more, the magnitude of the resulting coefficients confirms that PR&D is more productive in countries with high level of articles published. This result broadly confirms a strand of literature (before cited), which has documented the value of the scientific production in fostering the VC industry. In this case, scientific production is complementary to PR&D, implying that the benefits of PR&D on new VC commitments is increased if the scientific community is under conditions to intensify their production properly.

Next, we address aspects related with country infrastructure condition. Results obtained in this case are somewhat counterintuitive. The effect of PR&D on VC is stronger in countries with low infrastructure. In table 5, columns (1) and (2) PR&D and 3-year average PR&D interact with total previous year and 3-year average road

network for countries below and above of the sample media ( $Ps_{r+d} * Road_{low}$ ,  $Ps_{r+d} * Road_{high}$ ,  $Ps_{r+d} * Road_{low\_3year}$  and  $Ps_{r+d} * Road_{high\_3year}$ , respectively). The coefficients are positive, significant and their magnitude is higher in countries with lower road network for both cases, using the total previous year or 3-year average road network.

Table 6

**Early stage VC and Inst\_qual**

Independent variables	Early stage VC Investment			
	(1)	(2)	(3)	(4)
$Ps_{r+d}$	127,50			
	( 42.67)***			
$Ps_{r+d\_3\ year}$		143,65		
		(38.84)***		
$Ps_{r+d}*$			74,14	
Inst_qual_low			(61.37)	
$Ps_{r+d}*$			111,72	
Inst_qual_high			(46.84)**	
$Ps_{r+d\_3\ year}*$				100,94
Inst_qual_low_3 years				(64.95)
$Ps_{r+d\_3\ years}*$				118,38
Inst_qual_high_3 years				(52.27)**
Inst_qual	0,25	0,31	0,62	0,57
	(0.12)**	(0.11)***	(0.15)***	(0.19)***
Mar_cap	0,006	0,005	0,006	0,005
	(0.002)***	(0.001)***	(0.002)***	(0.002)***
Art_pub	0,011	0,011	0,011	0,012
	(0.002)***	(0.001)***	(0.002)***	(0.002)***
GDP	0,0313	0,027	0,02	0,024
	(0.007)***	(0.006)***	(0.007)***	(0.007)***
Constant	-0,35	-0,38	-0,35	-0,52
	(0.16)**	(0.16)**	(0.24)	(0.30)*
Time dummies	No	yes	No	yes
R <sup>2</sup>	0,46	0,43	0,47	0,36
Observations	389	425	355	349
Countries	38	38	35	34
Model	PCSE, het	PCSE, het	PCSE, ar(1), het	PCSE, het

It is known that the infrastructure favors profitability and volume of investment (Morrison & Schwartz, 1996; Justman, 1995; Kohei & Tabata, 2013). However, an explanation for the last result could be that the PR&D is more important for the generation of VC investments in countries with lower infrastructure. The conclusion is that in countries with less infrastructure PR&D becomes more important and these countries should make a greater effort in PR&D to increase the volume of VC. To check the robustness of this result in columns (3) and (4) PR&D and 3-year average PR&D interact with total previous year and 3-year average Public expenditure in gross fixed capital formation as percentage of GDP ( $Ps_{r+d} * Public\_fbk\_low$ ,  $Ps_{r+d} * Public\_fbk\_high$ ,  $Ps_{r+d} * Public\_fbk\_low\_3\ year$  and  $Ps_{r+d} * Public\_fbk\_high\_3\ year$ , respectively). As we mentioned in section 3.3, gross fixed capital formation is used as proxy for country infrastructure in this case. Significance, sign and magnitude of coefficients in columns (3) and (4) confirm the last conclusion: In countries with lower levels of infrastructure, the government decision for increasing PR&D is more important to foster VC activity. This finding can be related with the Finnish and Swiss economic development cases. Both countries are in the top ten VC activity of our sample, however they are not in high positions of the infrastructure investment ranking in the same sample proportionally. Culture (2010) mentions that the engine of 2011–2015 policy economic guide for development and productive transformation in Finland was the public

spending in research and innovation (it was allocated 114 euros per capita in PR&D). Finnish model, oriented to funding innovative startups, has positioned this country like the second innovative country of Europe (WEF, 2014). Switzerland has adopted a similar policy (SERI, 2013) and actually it is ranked like the first European innovative country (WEF, 2014).

**Sensibility to Stage, Level of Technology and Sector of Investment**

We advance testing the relation between PR&D and VC activity, specifically for three different kinds of investments: early stage (ES, tables 6 and 7), high technology (HT, tables 8 and 9) and manufacturing sector (MS, tables 10 and 11). Coefficients associated with public investment in research and development (Ps\_r+d) are positive and significant at 1 % in all three cases, implying that ES, HT and MS venture capital investments are higher in countries with higher PR&D (column 1 of tables 6,8,10).

Table 7

**Early stage VC, Road Paved and Art\_Pub**

Independent variables	Early Stage VC Investments			
	(1)	(2)	(3)	(4)
Ps_r+d*	147,77			
Art_pub_low	(65.90)**			
Ps_r+d*	223,84			
Art_pub_high	(54.98)***			
Ps_r+d_3 year*		136,47		
Art_pub_low_3 years		(45.85)***		
Ps_r+d_3 year*		231,91		
Art_pub_high_3 years		(43.31)***		
Ps_r+d*			105,37	
Road_low			(55.32)**	
Ps_r+d*Road_high			93,39	
Road_high			(47.07)**	
Ps_r+d*				131,13
Road_low_3 year				(54.71)**
Ps_r+d*				126,68
Road_high_3 year				(47.8)***
Inst_qual	0,30	0,30	0,27	0,36
	(0.17)*	(0.12)**	(0.1724)	(0.17)**
Mar_cap	0,006	0,006	0,009	0,007
	(0.002)***	(0.001)***	(0.002)***	(0.002)***
Art_pub	0,005	0,004	0,0104	0,011
	(0.002)**	(0.002)**	(0.0015)***	(0.002)***
GDP	0,033	0,037	0,028	0,022
	(0.011)***	(0.007)***	(0.01)***	(0.009)**
Constant	-0,62	-0,74	-0,29	-0,29
	(0.24)**	(0.15)***	(0.16)*	(0.17)
Time dummies	yes	yes	No	yes
R <sup>2</sup>	0,41	0,54	0,46	0,37
Observations	351	369	351	407
Countries	35	35	38	38
Model	PCSE ar(1), het	PCSE, het	PCSE, het	PCSE, het

Last result is checked using the 3-year average of public expenditure on R&D (Ps\_r+d\_3 year) as an explanatory variable; again coefficients are positive and significant at 1 % in all cases (column 2 of tables 6,8,10). In all models, the explicative variables' coefficients are estimated using control variables and outcomes associated to all of them follow consistently the expected behavior according to the theory. The emerging conclusion is that public investment in research and development is important, not only to encourage venture capital commitments in high technology investments, but also it benefits manufacturing industry and

firms in early stages of development. Other studies like Da Rin *et al.* (2006) suggest that increasing public R&D does not result in a higher early stage or high tech entrepreneurial ventures. A reason could be they use as dependent variable innovation and early stage ratios (HT-VC investment to total private equity –PE- investment and ES-VC investment to total VC investment). These measures do not take into account the increases in ES and HT venture capital investments when the total PE or total VC investment grows above ES and HT investments, and that can be critical, especially in years which PE and VC industry have had great expansions in general (for example some years in our sample).

Our conclusion is in line with the approach of Leyden and Link (1991) and David *et al.* (1992); these authors agree that technological knowledge and market information associated with publicly funded R&D could result in “spillovers” for firms in the same industry or related industry sectors. Acs *et. al* (2009) arguments are in the same line, they mention that spillovers increase the opportunities available to entrepreneurs and show a strong relationship between knowledge spillovers and new venture creation.

PR&D performed in academic and other non-profit institutions, including government laboratories could have positive spillover effects, particularly where the research produces general principles, tools and techniques, and access to skills that could rise the expected returns of commercially oriented applied R & D projects and as well as generate incentives to VC investment in diverse economic sectors.

Table 8

**High Tech VC and Inst\_Qual**

Independent variables	High Technology VC investment			
	(1)	(2)	(3)	(4)
Ps_r+d	204,38			
	(53.94)***			
Ps_r+d_3 year		273,81		
		(64.91)***		
Ps_r+d*			189,61	
Inst_qual_low			(60.87)***	
Ps_r+d*			213,05	
Inst_qual_high			(56.11)***	
Ps_r+d_3 year*				189,44
Inst_qual_low_3 year				(71.83)***
Ps_r+d_3 year*				273,57
Inst_qual_high_3 year				(68.35)***
Inst_qual	0,71	0,75	0,651	0,562
	(0.19)***	(0.19)***	(0.21)***	(0.205)***
Mar_cap	0,005	0,004	0,005	0,003
	(0.002)***	(0.002)**	(0.002)***	(0.002)*
Art_pub	0,013	0,015	0,013	0,014
	(0.002)***	(0.002)***	(0.002)***	(0.002)***

Independent variables	High Technology VC investment			
GDP	0,023	0,012	0,022	0,014
	(0.00)***	(0.00)	(0.00)***	(0.00)
Constant	-0,12	-0,27	-0,05	-0,03
	(0.257)	(0.25)	(0.27)	(0.29)
Time dummies	Yes	yes	Yes	yes
R <sup>2</sup>	0,47	0,40	0,48	0,42
Observations	402	437	402	403
Countries	39	39	39	39
Model	PCSE ar(1), het			

In column 3, we turn to analyze the characteristics of the country environment, but this time differentiating the



effects of PR&D over ES (table 6), HT (table 8) and MS (table 10) venture capital investments. We start interacting PR&D in countries with low ( $Ps_{r+d} * Inst\_qual\_low$ ) and high ( $Ps_{r+d} * Inst\_qual\_high$ ) level of Institutional quality, below or above the media, respectively. We find that the effect of PR&D on ES, HT and MS venture capital investments depends on institutional quality. Once again, coefficients show that the effect of PR&D is greater in countries with higher institutional quality for three kinds of VC investments studied, but for ES-VC investment the coefficient loses its significance when the institutional quality is low, indicating that institutional quality is particularly critical for these kinds of investments.

Table 9

**High Tech VC , Road Paved and Art\_Pub**

Independent variables	High Technology VC investment			
	(1)	(2)	(3)	(4)
Ps_r+d*	119,46			
Art_pub_low	(61.47)*			
Ps_r+d*	243,03			
Art_pub_high	(52.76)***			
Ps_r+d_3 year*		95,66		
Art_pub_low_3 year		(48.99)**		
Ps_r+d_3 year*		278,73		
Art_pub_high_3 year		(43.91)***		
Ps_r+d*			196,22	
Road_low			(69.34)***	
Ps_r+d*			157,83	
Road_high			(62.03)**	
Ps_r+d*				213,60
Road_low_3 year				(71.09)***
Ps_r+d*				211,63
Road_high_3 year				(63.03)***
Inst_qual	0,81	0,79	0,75	0,74
	(0.19)***	(0.14)***	(0.25)***	(0.23)***
Mar_cap	0,005	0,005	0,008	0,007
	(0.002)***	(0.001)***	(0.002)***	(0.002)***
Art_pub	0,009	0,008	0,013	0,014
	(0.002)***	(0.002)***	(0.002)***	(0.002)***
GDP	0,022	0,024	0,018	0,018
	(0.008)***	(0.007)***	(0.011)*	(0.011)*
Constant	-0,053	-0,225	-0,027	-0,211
	(0.266)	(0.179)	(0.277)	(0.256)
Time dummies	Yes	Yes	Yes	Yes
R <sup>2</sup>	0,49	0,54	0,49	0,44
Observations	402	437	351	409
Countries	39	39	38	39
Model	PCSE ar(1), het			

The last result coincides with early stage investments characteristics. Because these investments are associated with high uncertainty, more risk and greater difficult of monitoring, a greater possibility exists for potential moral hazard and adverse selection problems in relations established by venture capitalist (Amit, Brander & Zott, 1998; Gompers 1995; Kaplan & Stromberg 2004). Without strong institutions enforcing deals, governmental efforts in PR&D loose their productivity to generating VC activity. Coefficient reduction for low institutional quality when the model is calculated interacting 3-year average public spending on R&D with low ( $Ps_{r+d\_3\ year} * Inst\_qual\_low\_3\ year$ ) and high ( $Ps_{r+d\_3\ year} * Inst\_qual\_high\_3\ year$ ) 3-year average institutional quality for the three kind of VC Investment (column 4 in tables 6, 8 and 10), confirms that PR&D reduces its productivity generating VC investments in that case.

We also find that PR&D increases its productivity to generate ES (table 7), HT (table 9) and MS (table 11) VC

investments in countries with higher level of articles published. Once again, results are confirmed interacting PR&D in countries with low ( $Ps_{r+d} * Art\_pub\_low$ ) and high ( $Ps_{r+d} * Art\_pub\_high$ ) level of articles published (column 1) and 3-year average public spending on R&D with low ( $Ps_{r+d\_3\ year} * Inst\_Art\_pub\_3\ year$ ) and high ( $Ps_{r+d\_3\ year} * Art\_pub\_high\_3\ year$ ) 3-year average articles published (column 2). An issue of interest is that coefficients associated with the relationship between ES, HT and MS venture capital investments and PR&D interacting with high level of articles published increases its value 1.4, 1.7 and 2.1 times compared with coefficients associated to the relationship between total venture capital investments and PR&D, interacting with high level of articles published.

Table 10

**Manufacturing VC and Inst\_Qual**

Independent variables	Manufacturing VC investment			
	(1)	(2)	(3)	(4)
Ps_r+d	269,11			
	(56.96)***			
Ps_r+d_3 year		287,91		
		(52.01)***		
Ps_r+d*			212,88	
Inst_qual_low			(62.36)***	
Ps_r+d*			299,91	
Inst_qual_high			(59.03)***	
Ps_r+d_3 year*				200,69
Inst_qual_low_3 year				(68.61)***
Ps_r+d_3 year*				312,86
Inst_qual_high_3 year				(58.07)***
Inst_qual	0,62	0,63	0,41	0,43
	(0.18)***	(0.17)***	(0.19)**	(0.19)**
Mar_cap	0,001	0,001	0,001	0,001
	(0.002)	(0.001)	(0.002)	(0.002)
Art_pub	0,016	0,016	0,015	0,015
	(0.002)***	(0.002)***	(0.002)***	(0.002)***
GDP	0,002	0,003	0,001	0,002
	(0.008)	(0.007)	(0.008)	(0.008)
Constant	-0,372	-0,433	-0,098	-0,069
	(0.253)	(0.232)	(0.272)	(0.299)
Time dummies	no	yes	no	yes
R <sup>2</sup>	0,380	0,354	0,392	0,379
Observations	403	438	403	387
Countries	39	39	39	37
Model	PCSE, ar(1), het			

Last results are in line with the efficiency of PR&D conceptual framework (Conte *et al.*, 2009). PR&D is a framework input whose primary objective is to produce an output, represented in increasing the innovative output (efficiency) and consequently to yield an outcome signified in rising competitiveness, productivity and economic growth (effectiveness). Innovative output may be proxy by articles published (Moed *et al.*, 1985; Mowery & Rosenberg, 1979) therefore, a larger number of articles published imply higher PR&D efficiency. Thus, our greater coefficients obtained in the last paragraph indicate PR&D is more productive to fostering ES, HT and MS venture capital investments in countries with higher PR&D efficiency (more opportunities for VC investments) and should be inferred, better PR&D effectiveness (greater return for VC investments). Finally, the pattern founded in the relation between total VC investments and PR&D interacting with road network conserves the same behavior for ES (table 7) and HT (table 9), but not for MS (table 11) venture capital investments.

For the first two, again the effect of PR&D on VC is stronger in countries with low infrastructure. This is confirmed using PR&D (column 3) and 3-year average PR&D (column 4) interacting with total previous year and 3-year average road network for countries below and above of the sample media ( $Ps_{r+d} \cdot Road_{low}$ ,  $Ps_{r+d} \cdot Road_{high}$ ,  $Ps_{r+d} \cdot Road_{low\_3\ year}$  and  $Ps_{r+d} \cdot Road_{high\_3\ year}$ , respectively). The coefficients are positive, significant and its magnitude is higher in countries with lower road network for both cases.

Table 11

**Manufacturing VC, Road Paved and Art\_Pub**

Independent variables	Manufacturing VC investment			
	(1)	(2)	(3)	(4)
$Ps_{r+d}^*$	162,66			
Art_pub_low	(60.39)***			
$Ps_{r+d}^*$	337,11			
\ Art_pub_high	(52.03)***			
$Ps_{r+d\_3\ year}^*$		159,39		
Art_pub_low_3 year		(45.25)***		
$Ps_{r+d\_3\ year}^*$		343,97		
Art_pub_high_3 year		(41.64)***		
$Ps_{r+d}^*$			196,62	
Road_low			(74.79)***	
$Ps_{r+d}^*$			202,25	
Road_high			(66.02)***	
$Ps_{r+d}^*$				243,49
Road_low_3 year				(62.16)***
$Ps_{r+d}^*$				257,73
Road_high_3 year				(54.83)***
Inst_qual	0,726	0,728	0,408	0,530
	(0.179)***	(0.122)***	(0.226)*	(0.209)**
Mar_cap	0,001	0,001	0,004	0,003
	(0.002)	(0.001)	(0.002)**	(0.002)
Art_pub	0,009	0,009	0,014	0,014
	(0.002)***	(0.002)***	(0.002)***	(0.002)***
GDP	0,003	0,008	0,020	0,012
	(0.008)	(0.007)	(0.010)*	(0.009)
Constant	-0,342	-0,472	-0,304	-0,432
	(0.240)	(0.159)	(0.277)	(0.221)**
Time dummies	No	yes	No	yes
R <sup>2</sup>	0,42	0,50	0,40	0,37
Observations	403	438	352	410
Countries	39	39	38	39
Model	PCSE, ar(1), het			

The relation between MS venture capital investments and PR&D interacting with road network shows a different behavior. PR&D is more productive generating MS venture capital investments in countries where level of road network is high (table 11). The result is checked using PR&D (column 3) and 3-year average PR&D (column 4) interacting with total previous year and 3-year average road network for countries below and above of the sample media ( $Ps_{r+d} \cdot Road_{low}$ ,  $Ps_{r+d} \cdot Road_{high}$ ,  $Ps_{r+d} \cdot Road_{low\_3\ year}$  and  $Ps_{r+d} \cdot Road_{high\_3\ year}$ , respectively). Having greater road network increases significantly the positive effect of PR&D on motivating new MS venture capital commitments to get in the profitability chase.

**Conclusions**

We use a large panel of 40 countries over the 1998 to 2012 to identify the impact of PR&D on venture capital investment. We use the Thomson ONE Database, which includes data of 276.051 venture capital deals in the studied period. We find that PR&D has a sizeable effect on venture capital investments: numerically, an increase of 1 % in PR&D as a share of GDP increases the VC investments on average 36,620.7 dollars per inhabitant economically active. This effect is relatively higher in countries with higher level of institutional quality, and higher level of articles published. Also, we find that PR&D is more important for the generation of VC investments in countries with lower infrastructure.

Effects mentioned above hold for different VC investment proxies and stand when we correct for possible endogeneity in venture capital investment series, by using a difference and system GMM dynamic panel estimator model with a collapsed instrument matrix and two lags, obtaining more robust conclusions. The effect of PR&D on VC investments is robust accounting other time and country characteristics which has been considered in the literature as important determinants of VC activity.

Also, we find that PR&D is specifically important for Early Stage (ES), High Technology (HT) and Manufacturing Sector (MS) venture capital investments. Institutional quality increases the positive effect of PR&D on ES, HT and MS venture capital investments. Results show that the influence of PR&D is greater in countries with higher institutional quality for three kinds of VC investments studied. However, For ES-VC investment, PR&D loses its significance when the institutional quality is low, indicating that institutional quality is critical for these kinds of investments. We also find that PR&D increases its productivity to generate ES, HT and MS VC investments in countries with higher level of articles published. These results are in line with the efficiency of PR&D conceptual framework (Conte *et al.*, 2009) and with the Knowledge Spillover approaches from Leyden and Link (1991), David *et al.* (1992) and Acs *et al.* (2009).

Finally, the pattern found in the relation between total VC investments and PR&D interacting with road network maintains the same behavior for ES and HT but not for MS venture capital investments. PR&D is more productive generating MS venture capital investments in countries where level of road network is high. Having greater road network increases significantly the positive effect of PR&D in the motivation of new MS venture capital commitments. However, the effect of PR&D on ES and HT VC investments is stronger in countries with low infrastructure, the conclusion is that in these last kind of countries PR&D becomes more important, and they should make a greater effort in PR&D to increase the volume of VC activity. All our results strongly suggest that PR&D is conducive to generating and increasing the attractiveness of venture capital investment opportunities.

In this paper we seek to address how PR&D can affect some factors that could increase or reduce the expected rate of return for VC investments. Outcomes indicate that as aggregated economic the net effect is positive, and PR&D does seem to generate value through

fostering VC activity in the economy. However, a number of important questions remain unanswered due to the nature of our data. For example, what is the relative importance of the different channels via which PR&D affect VC investments? A second question arises to establish what kind of PR&D is more productive in generating VC activity; further research could classify PR&D according to its short-

time objectives (basic or applied) or according with the strategy used (for example, Tax incentives or direct subsidies). A third issue to be analyzed could be to determinate how PR&D impacts VC investment in different economic sectors. Future research can greatly contribute by addressing those questions.

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