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The comovement between venture capital and innovation in China: what are the implications?

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Abstract This study investigates the long-run co-movement between venture capital and technological innovation for 28 provinces (including autonomous regions) in China, using the panel cointegration and panel-based error correction model over the 2001–2012 period. Our results confirm that venture capital and innovation have long-run cointegrated relationships as well as bidirectional causality for the whole country. Analysis of sub-samples again discovers similar results in both the eastern and central regions, but not in the western region. The policy implication shows that China's development of innovations should be based on more venture capital input and that the government should establish a long-run innovation policy to accelerate the development of venture capital. We also offer several constructive suggestions for governments in the western provinces.

Keywords Venture capital · Innovation · Panel cointegration · Causality

JEL Classification G24 · O32 · C33

1 Introduction

The relationship between innovation and venture capital (VC) has attracted a lot of attention in the field of innovation research. In principle, venture capital mainly aims to mitigate the financing constraint when enterprises are faced with the start-up process (Kortum and Lerner 2000; Bottazzi and Da Rin 2002). Venture capitalists also provide funds for enterprises undergoing innovative start-ups (Kortum and Lerner 2000; Arque-

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Catells 2012). The traditional literature has put forward the suggestion that venture capitalists may exhibit expropriation behavior that can influence innovation from multiple perspectives, such as national, industrial, and firm innovations (Hsu 2004; Atanasov 2006; Popov and Rossenboom 2012; Faria and Barbosa 2014). However, Bhide (2000) and Hirukawa and Ueda (2011) uphold a different view challenging the notion that venture capital may impede innovation. These findings are, however, based on a one-way causal relationship, which specifically brings up a question: Do the obtained conclusions represent empirical, cross-sectional results? Another issue arises when we assume the invested enterprises have more innovations: Is it worthwhile for the firm to attract more venture capital inflows or not?

We note that previous literature mostly focuses on the unidirectional causality running from venture capital to improved innovation as being a priori, whereas the reverse feedback is commonly neglected and does not seem to be identified. In particular, Hirukawa and Ueda (2011) and Geronikolaou and Papachristou (2012) prove a causal direction running from great innovation to considerable venture capital absorption. Therefore, do relationships exist that run from considerable venture capital absorptions to great innovation? Do venture capital and innovation exhibit a long-run co-movement? Moreover, what is the actual causal relationship among the variables? Most of the present literature offers unclear answers and even uses only developed economies as the main focus of analysis. This in turn gives rise to a topic that needs to be carefully thought through, because different results may be discovered for developing countries, such as China. To avoid the heterogeneous problem on the samples selected, Chang and Lee (2011) also mention that dissimilarities in both regional development and levels of development should be considered in the empirical process.

Panel data estimation provides more powerful tests and estimates, allowing us to collect the information available coming from cross-sectional data (Chang and Lee 2010). Thus, through the use of Pedroni's (2004) heterogeneous panel cointegration tests, the purpose of this paper is to first empirically examine the long-run co-movement and causal relationship between VC and innovation using the number of patent applications (*Patent*) and the total amount of VC investment (*Asset*) as well as the number of VC investment projects (*Proje*ct) in a bivariate model for the period 2001–2012 in China.[1] Second, once we establish that the variables are structurally related, we shall estimate the long-run equations by employing the panel dynamic ordinary least squares (DOLS) and discover the path toward equilibrium.[2] Third, we implement the panel-based error correction model (VECM), which contributes to distinguishing between the short-run and long-run causalities among the variables. Via these econometric investigations, we can find the short-run and long-run causalities among *Patent*, *Asset*, and *Proje*ct when we consider the data's properties and by adopting the suitable econometric method. Fourth and finally, in order to see if the VC and innovation relationship differs throughout China, we also divide the sample into regional provinces.[3] The results herein should clear up questions in earlier studies regarding the relation between VC and innovation.

[1] We follow the selection of proxy variables in Popov and Rossenboom (2012) as well as in Anokhin and Schulze (2009).

[2] Heterogeneity reflects, for instance, the difference in living standards or economic development among the sample provinces; traditional works mainly use an estimation of instrumental variables (Kortum and Lerner 2000) or a quasi-natural experiment (Bertoni et al. 2010; Arque-Catells 2012) to control for endogeneity in regards to the influence of venture capital on innovation.

[3] We consider the availability of data and the serious deficiencies of venture capital investment data and innovation for Hainan, Qinghai, and Tibet provinces.

The traditional literature in this field has mostly focused on unidirectional causality running from VC to innovation. For example, Kortum and Lerner (2000) apply a patent production function to analyze the influence of VC on a firm's innovation and regress the number of patents on venture capital investment as well as traditional R&D input. The authors figure out the causal relationship between VC and an enterprise's innovation in 20 U.S. manufacturing industries, providing similar results to those of Baum and Silverman (2004) for the case of Canada and those of Popov and Rossenboom (2012) for the case of European countries. We also notice that traditional scholars commonly apply the patent production function to analyze VC's influence on firm innovation (Tykvova 2000; Hasan and Wang 2006). Through the enterprise perspective, researchers have also studied VC's influence on innovation, but this is not usually done in accordance with the patent production function as the theoretical framework (Engel and Keilbach 2007; Hellman and Puri 2000; Baum and Silverman 2004). Zucker et al. (1998), Bhide (2000), and Chemmanur et al. (2011) challenge that VC may present a negative linkage with innovation, because in the pursuit of greater investment opportunity and less uncertainty, investors usually carry out due diligence and continually monitor those invested firms. Zucker et al. (1998) point out that this in turn impedes innovation.

We find relatively rare research concerning that innovation may lead to venture capital. Arque-Catells (2012) emphasizes that venture capitalists commonly prefer the commercialization of innovations that already have the basic innovative environments and performance. In other words, a country with a higher level of innovation and technology usually has a higher probability to attract more attention of investors, which also is accompanied by large capital investment. Therefore, a sound innovation environment and performances are thus reasonable from any great increase of VC input. Beyond this, we believe that such a situation can apply to industrial and regional development, in which the possible effects from an increase in innovations that normally tend to increase technology would be more than compensated for by the positive effects on VC inflows.

Table 1 lists the most recent papers pertaining to VC and innovation, with most scholars focusing on the U.S. (see Kortum and Lerner 2000; Hirukawa and Ueda 2011) or European countries (see Popov and Rossenboom 2012; Geronikolaou and Papachristou 2012; Faria and Barbosa 2014), and no works examining developing markets. With the exception of Caselli et al. (2009), these papers have employed the panel data approach, while mostly ignoring the cointegrated relationship among variables. We also note that the panel causality technique has never been applied to determine the VC-innovation relationship.

The advantages of an individual country analysis are that it can keep track of country properties and also lead to a more accurate interpretation. Arestis et al. (2001) argue that this method can provide useful insights into differences in such relationships across countries and may illuminate important details that are hidden in averaged-out results. Chang and Lee (2009) hence point out that time series studies of an individual economy offer critical advantages over cross-country growth regressions. Particularly, China provides an interesting case for several reasons. First, this country has enjoyed a remarkable growth rate of approximately 10 % per annum in the past few decades, which has created substantial changes in the structure of production in the nation's industrial sectors. Second, a rapid increase in the opening up of financial markets implies that more reliance should be placed upon capital investment in the process of an industry-led strategy. In this regard, there is a large volume of previous works focusing on unitary country analysis between VC and technology innovation—see Baum and Silverman (2004) for Canada, Engel and Keilbach (2007) for Germany, Tang and Chyi (2008) for Taiwan, Caselli et al. (2009) for Italy, and Arque-Catells (2012) for Spain.

Table 1 Comparative survey of the empirical results from various empirical works

Author(s)	Model	Period	Subject	Causal relationship
Kortum and Lerner (2000)	Panel instrumental variable regression	1965–1992	Panel of 20 U.S. manufacturing industries	VC $\overset{\rightarrow}{+}$ Innovation
Romain and Van Pottelsberghe de la Potterie (2004)	Panel generalized least squares (GLS) model	1990–2001	Panel dataset of 16 OECD countries	VC $\overset{\rightarrow}{+}$ Innovation
Baum and Silverman (2004)	Panel random effect Poisson model and GLS estimation method	1991–2000	852 observations in Canada	VC $\overset{\rightarrow}{+}$ Innovation
Da Rin and Penas (2007)	Probit regressions; multinomial logit regression	1998–2004	91 VC-backed and 7808 non-VC- backed samples from the Netherlands	VC $\overset{\rightarrow}{+}$ Innovation strategies
Caselli et al. (2009)	Difference-in-difference method after propensity score matching	1995–2004	37 venture-backed firms in non-venture-backed IPOs in Italy	Innovation $\overset{\rightarrow}{+}$ VC
Bertoni et al. (2010)	Panel GLS models	1994–2003	33 venture-backed and 318 twin firms in Italy	VC $\overset{\rightarrow}{+}$ Innovation
Hirukawa and Ueda (2011)	Panel autoregressive distributed lag model and Granger causality test	1968–2001	19 industries in the U.S	VC $\overset{\rightarrow}{+}$ Innovation
Popov and Rossenboom (2012)	Panel OLS regression; Tobit regression; 2SLS regression	1991–2005	21 European countries and 10 manufacturing industries	VC $\overset{\rightarrow}{+}$ Innovation (measured by patents; in a high VC country)
Geronikolaou and Papachristou (2012)	Panel dynamic generalized method of moments model	1995–2004	Annual data for 15 European countries	Innovation $\overset{\rightarrow}{+}$ VC
Arque-Catells (2012)	Dynamic panel Tobit model	1998–2009	2000 Spanish manufacturing firms	U-shape relationship between VC and innovation.
Faria and Barbosa (2014)	Panel dynamic system generalized method of moments model	2000–2009	Panel data of 17 European Union countries	VC $\overset{\rightarrow}{+}$ Innovation (measured by patents)

"+" positive influence; "VC → Innovation" denotes causality running from venture capital to innovation; "Innovation → VC" denotes causality running from innovation to venture capital; "VC↔ Innovation" denotes bi-directional causality between venture capital and innovation

To investigate the previous debates in greater depth, this study first applies a heterogeneous panel cointegration technique as well as VECM to investigate the relationship between VC and innovation performance across 28 provinces in China, including municipalities and autonomous regions. Overall, our evidence shows that there is a long-run steady-state relationship between venture capital and innovation for the full sample of Chinese provinces, and a long-run bi-directional causality between variables is discovered. We also explore different group issues that are of concern to eastern, central, and western China. There are interesting disparities in which a long-run cointegrationed relationship and bi-directional causality exist in the eastern and central regions, but not in the western region. Provincial governments located in the west should particularly notice such a phenomenon if they attempt to develop an innovation industry according to venture capital inputs.

The previous literature has also documented that the expropriation effect often appears in the invested enterprise and the influences are quite significant. In this regards, VC investors can utilize their own industrial and information advantages to expropriate innovative projects and ideas from the investee (Caselli et al. 2009; Cheung et al. 2010). Generally speaking, previous wisdom discovers that greater expropriation is more likely to suppress innovative behavior of the invested enterprise; such arguments are commonly seen in several famous works. For instance, Engel and Keilbach (2007) offer empirical evidence that, in the initial stage of the venture capital inflow, most German firms apparently divert their attention from technology R&D to commercialization, which results in a shock at reducing innovation. In this line, Atanasov (2006) also mention that venture capitalists expropriate ideas from venture-backed firms commonly at the seed or early venture stage. Faria and Barbosa (2014) again point out that such expropriated behavior is one of the potential costs of VC investment using the sample of 17 European Union countries.

Based on the above research design, we put forth three interesting, albeit contradictory theories. First, if uni-directional causality runs from VC to innovation, then it indicates that VC capital attraction is an impetus for innovative performance. Second, if uni-directional causality runs from innovation to VC, then the implementation of innovative policies will first enhance VC absorption; the implication is that a reduction in the amount of innovative products would likely negatively affect VC. Third and finally, we note the evidence of absent causality in either direction, which we call it as 'neutrality hypothesis' and which signifies that VC does not affect innovation whatsoever.

The paper is organized as follows. Section 2 provides a brief discussion of the panel unit root test and the panel cointegration procedure. Section 3 presents empirical results. Section 4 concludes.

2 Econometric methodology and model

To investigate the panel cointegrated relationships among venture capital and innovation in two selected groups, we first use the time series panel regression tests of Pedroni (2004), which follow fixed effect panel regressions:

$$y_{it} = \alpha_i + x_{it}^{'}\beta_i + u_{it}, \quad i = 1, \ldots, N,\ t = 1, \ldots, T, \tag{1}$$

where y_{it} is the dependent variable, and $Patent_{it}$ measures the domestic innovative activity through the number of patent applications filed by residents and non-residents in each year of the study; we treat it as the innovation output variable. To ensure robustness of our results, x_{it} represents two measures for the investment of venture capital.

Following Bottazzi and Da Rin (2002) and as noted above to ensure robustness of our results, we use two measures of VC investment. First, we choose the total amount of capital managed by venture capital (*Asset*, RMB 10,000). Second, we select the number of VC investment funds, *Project*, to measure the development of provincial venture capital.[4] Both the innovation and VC variables have the dimensions $(N \times T) \times 1$ and $(N \times T) \times M$, where N refers to the number of individual provinces in the panel, T refers to the number of observations over time, M refers to the number of regression variables, and u_{it} is the estimated residual. The parameters α_i allow for the possibility of province-specific fixed effects, and deterministic trends are also permitted to vary by individual. Hence, in general the cointegrating vectors may be heterogeneous across members of the panel with asymptotic and finite-sample properties in the testing statistics (Pedroni 2004). Heterogeneity exists within different economic growth rates, and differences in cross-province innovative performance also raise important econometric issues. The tests allow for heterogeneity among individual members of the panel, including heterogeneity in both the long-run cointegrating vectors and in the dynamics, since there is no reason to believe that all parameters are the same across provinces.

Pedroni (2004) mentions residual-based tests with two types. All tests are distributed as being standard normal asymptotically. The first four statistics necessitates pooling the residuals of the regression for the within-group sample, including the panel v-statistic, panel ρ-statistic, panel PP-statistic, and panel ADF-statistic. Hence, the other category of three statistics includes the group ρ-statistic, group PP-statistic, and group ADF-statistic. These statistics are in accordance with estimators that simply average the individually estimated coefficients for each member. Particularly, the panel v-statistic diverges to positive infinity and is a one-sided test, where large positive values reject the null of no cointegration; the remaining statistics diverge to negative infinity, meaning that large negative values reject the null of no cointegration. All these tests are able to accommodate individual specific short-run dynamics, individual specific fixed effects, and deterministic trends as well as individual specific slope coefficients (Pedroni 2004).

In the estimated steps, if the cointegrated relationship of the variables is determined, then one can next estimate the cointegrated vectors. However, the traditional bias-corrected OLS estimator does not in general show improvement over the OLS estimator. Thus, Stock and Watson (1996) suggest that alternatives, such as the Fully Modified Ordinary Least Square (MOLS) esimator or the DOLS estimator, may be more promising in cointegrated panel regressions. Additionally, Kao and Chiang (2000) note that the panel DOLS is not only fully parametric, but also combines with the leads and lags of the independent variables in the estimated model. It thus offers a computationally convenient alternative to the panel FMOLS estimator.

The process u_{it} in Eq. (1) can be written as:

$$u_{it} = \sum_{j=-\infty}^{\infty} \phi_{ij}\varepsilon_{it+j} + v_{it}, \tag{2}$$

where v_{it} is stationary with zero mean and absolutely summable, ϕ_{it} is smaller than infinity, and v_{it} and ε_{it} are uncorrelated contemporaneously with all lags and leads. We next propose a DOLS estimator that uses the past and future values of independent variable x_{it} as additional regressors. We then substitute Eq. (2) into Eq. (1) to get:

[4] We gather *Applications*, *Asset*, and *Project* from the China Statistical Yearbook: the Intellectual Property.

$$y_{it} = \alpha_i + x_{it}^{'}\beta + \sum_{j=-q}^{q} \phi_{ij}\Delta x_{it+j} + \dot{v}_{it}, \quad \text{where} \quad \dot{v}_{it} = v_{it} + \sum_{j>q} \phi_{ij}\varepsilon_{it+j}. \tag{3}$$

Therefore, we obtain the DOLS of the estimator by running the following regression:

$$y_{it} = \alpha_i + x_{it}^{'}\beta + \sum_{j=-q}^{q} \phi_{ij}\Delta x_{it+j} + \dot{v}_{it}. \tag{4}$$

Hence, we introduce that, in the empirical model, x_{it} includes both levels of our two observed venture capital variables (*Asset* and *Project*).

Perman and Stern (2003) propose that while other traditional studies often neglected the endogeneous problems of most of the independent variables, this may have generated an estimated bias. To improve upon this, the panel cointegration test and DOLS estimation can be adopted to replace the traditional panel model (Kao and Chiang 2000; Pedroni 2004); such methods combine to offer several advantages: the panel approach merges both time series and cross-section information from the data; panel cointegration tests allow researchers to catch the heterogeneous long-run relationships between variables; panel DOLS has the characteristics of a dynamic cointegrated relationship for those specific provinces; and panel estimation considers the endogenous problems of regressors (Westerlund et al. 2015; Jäger and Schmidt 2016). Furthermore, the dynamic panel VECM technique allows us to identify both short-run and long-run causalities among *Patent*, *Asset*, and *Project* (Chang and Lee 2010).

3 Empirical results

Our study uses annual time series for the 28 provinces in China. On the basis of existing research, this study measures the innovation output variable through the number of patent applications (*Patent*). We hence choose the amount of VC investment (*Asset*) and number of VC investment projects (*Project*) to measure the development of provincial venture capital. Annual data for *Patent*, *Asset*, and *Project* are obtained from China Statistical Yearbook (2014). The empirical period depends on the availability of data, where the time period used is 2001–2012. *Asset* is measured in per capita terms at constant 2001 prices and transformed into natural logarithms.

3.1 Results of panel unit root and panel cointegration test

The panel cointegration analysis consists of several steps. In the beginning, a panel unit root (two statistics proposed by LLC and UB tests) is first tested. Additionally, we test the cointegration panel data by using the heterogeneous panel cointegration test proposed by Pedroni (2004). We then estimate the long-run relationship using the DOLS technique for heterogeneous cointegrated panels (Pedroni 2000). Finally, once the panel cointegration is implemented, we follow Chang and Lee (2010) to establish a panel error correction model to look for short-run and long-run causalities between *Patent-Asset* and *Patent-Project.*

Table 2 presents the panel unit root tests, showing that the statistics of the levels of all variables have a unit root. Furthermore, the results in all variables that are first-differenced exhibit stationary behaviour and imply that all the variables with significance at the 5 % level follow the I (1) process. Using these results, we further test *Patent-Asset* as well as

Table 2 Panel unit root tests

	LLC	UB
Patent	0.848	−0.743
Project	−0.027	0.236
Asset	−0.584	−0.847
Δ*Patent*	−4.658**	−5.615**
Δ*Project*	−6.434**	−3.624**
Δ*Asset*	−5.146**	−4.934**

LLC and UB tests indicate Levin et al. (2002) and Breitung (2000) panel unit root tests, respectively, which are under the null of without a unit root. Δ denotes first differences. All variables are in natural logarithms

** Indicates statistical significance at the 5 % level

Table 3 Pedroni's (2004) panel cointegration tests—full sample

	Patent versus *Asset*	*Patent* versus *Project*
Panel variance	1.988**	3.636**
Panel ρ	−3.381**	−3.530**
Panel PP	−6.362**	−6.023**
Panel ADF	−5.892**	−5.400**
Group ρ	−0.654	−0.901
Group PP	−6.286**	−4.661**
Group ADF	−5.944**	−4.740**

Statistics are asymptotically distributed as normal. The variance ratio test is right-sided, while the others are left-sided

** and * Denote rejecting the null of no cointegration at the 5 and 10 % levels, respectively

Patent-Project for cointegration in order to determine if there is a long-run relationship when controlling for an econometric specification.

Table 3 shows Pedroni's (2004) panel cointegration test of the basic model, which provides two types of tests. The first type is based on the within-dimension approach (which includes the panel variance, panel-ρ, panel PP, and panel ADF statistics) and pools the autoregressive coefficients across different sample provinces for the unit root tests on the estimated residuals. The second type is based on the between-dimension approach (which includes the group-ρ, group PP, and group ADF statistics) and simply averages the individually estimated coefficients for each sample province. In addition, the panel variance statistic is a one-sided test where large positive values reject the null hypothesis of no cointegration. The remaining statistics diverge to negative infinitely, which means that large negative values reject the null.[5]

Note that in Table 3, except for the Group ρ statistic, all other statistics significantly reject the null of no cointegration no matter for the combination of *Patent-Asset* or *Patent-Project*. Given these tests' results, we believe that the number of patent applications in China's provinces has a long-run cointegration relationship with VC and innovation.

[5] The critical values of panel cointegration tests are tabulated by Pedroni (1999).

3.2 Results of panel long-run estimate

After confirming the existence of a long-run relationship between venture capital and innovation, we further use the panel DOLS estimation proposed by Kao and Chiang (2000) to determine the province-by-province and panel estimators, which are shown at the bottom of the table. In Table 4, when the model is *Patent-Asset* as shown in column 2, the coefficient of *Asset* is statistically significant at the 5 % level, and the effect is positive. On a per province basis, *Asset* has a positive impact on *Patent* except for Anhui, Beijing, Fujian, Gansu, Heilongjiang, Jilin, Jiangxi, Shanxi, Shaanxi, and Shanghai, where the statistical significance is at the 5 % level. Moreover, for eleven provinces (Chongqing, Guangxi, Guizhou, Hebei, Henan, Hubei, Hunan, Jiangsu, Sichuan, Tianjin, Yunnan), the coefficient of *Asset* is positively significantly larger than 1. When the dependent variable is *Asset*, the panel test results of *Patent* also reject the null at least at the 5 % level of significance, and the panel estimator is 2.129. On a per province basis, in 12 provinces *Patent* has a positive impact on *Asset* where the statistical significance is at the 5 % level. Only one province (Anhui) has a coefficient of *Patent* that is significantly larger than 1.

Table 5 presents the DOLS estimation for the combination of *Patent-Project*. When the dependent variable is *Patent,* there is a positive sign for the panel estimation of *Project*, where the coefficient (0.189) is statistically significant at the 5 % level. On a per province basis, 15 provinces have a significantly positive sign, where the statistical significance is at the 5 % level. Moreover, when the dependent variable is *Project*, the panel coefficient (3.577) of *Patent* still remains statistically significant at the 5 % level, and the effect is positive. On a per province basis, *Patent* has a positive impact on *Project* where the statistical significance is at the 5 % level in 12 out of 28 provinces. Given the estimated results of Tables 4 and 5, they display that no matter how dependency runs, *Patent* and *Asset* present a positive long-run correlation with each other.

To conclude, the province-by-province and panel cointegration test results clearly indicate that there is a cointegrating relationship between venture capital and innovation in China. Our conclusion matches up with Kortum and Lerner (2000) as well as Tykvova (2000), who reveal a significantly positive relationship between VC and patent applications. Though the panel results provide clear evidence that there is a fairly strong long-run relationship between innovation and venture capital, interestingly, in six provinces—Beijing, Gansu, Jilin, Jiangxi, Shaanxi, and Chongqing, there is a bi-direction negative cointegration between venture capital and innovation.[6] Why is this so? Kortum and Lerner (2000) indicate that there are two types of venture capital accelerating innovation. One is that venture capitalists mitigate the problem of underinvestment in innovative activities for those small and new firms (Samila and Sorenson 2011), and the other is that venture capitalists can help new firms to grow fast and become profitable (Sahlman 1990). However, two different processes imply an essential hypothesis that these small and new firms should first have proven technology and then the capitalists will invest in these companies. Jiangxi, Shaanxi, Gansu, and Chongqing provinces not only have restricted their location factors from absorbing and creating new technology effectively and rapidly, but also lack a perfect communication mechanism with venture capitalists. The relative lower innovation level and location factors cause a vicious circle between venture capital and innovation. Jilin, which has a traditional industrial base going back to the 1950s, may

[6] Beijing's negative influence between venture capital and innovation implies that venture capitalists prefer profitable items like REITs and other financial services there. In the future we shall research on whether real estate or other financial industries influence venture capital and innovation.

Table 4 DOLS long-run estimates: *Patent* versus *Asset*—full sample

Variable	Dependent variable is *Patent*	Dependent variable is *Asset*
Anhui	−3.026 (−8.480) **	1.495 (3.002)**
Beijing	−20.661 (−2.245)**	−0.024 (−1.857)*
Chongqing	3.495 (17.535)**	0.227 (1.028)
Fujian	−3.949 (−4.958)**	−0.081 (−1.515)
Gansu	−4.080 (−1.648)*	−0.217 (−3.979)**
Guangdong	−0.665 (−1.027)	0.257 (13.410)**
Guangxi	1.247 (7.264)**	0.629 (7.825)**
Guizhou	5.783 (7.566)**	0.072 (1.272)
Hebei	3.686 (4.949)**	0.335 (5.787)**
Henan	3.181 (10.773)**	0.211 (4.183)**
Heilongjiang	−1.368 (−2.677)**	−0.306 (−1.412)
Hubei	3.390 (2.332)**	0.053 (0.811)
Hunan	7.657 (4.869)**	0.133 (5.115)**
Jilin	−1.432 (−4.542)**	−0.699 (−9.973)**
Jiangsu	2.492 (19.943)**	0.446 (52.588)**
Jiangxi	−2.857 (−2.982)**	−0.221 (−16.590)**
Liaoning	−0.458 (−0.842)	0.591 (0.956)
Inner Mongolia	0.856 (1.493)	0.298 (11.999)**
Ningxia	−0.097 (−0.292)	−0.346 (−0.751)
Shandong	−0.831 (−1.029)	−0.607 (−8.859)**
Shanxi	−1.456 (−2.795)**	0.236 (2.275)**
Shaanxi	−1.134 (−7.539)**	−0.551 (−8.283)**
Shanghai	−3.812 (−3.731)**	0.062 (0.780)
Sichuan	1.315 (3.688)**	0.884 (12.287)**
Tianjin	1.549 (2.192)**	0.056 (0.403)
Xinjiang	0.820 (4.613)**	0.205 (3.268)**
Yunnan	4.155 (6.990)**	0.104 (4.857)**
Zhejiang	−0.049 (−0.077)	0.631 (4.569)**
Panel	0.770 (7.485)**	2.129 (13.789)**

t statistics in parenthesis.

** (*) indicates statistical significance at the 5 % (10 %) level

allow this lack of innovation impetus since its economic structure may prefer traditional heavy industry (Wang 2004; Xu and Zhang 2011).[7] Finally, Cheng (2013) argue that venture capitalists favor profitable items like Real Estate Investment Trusts (REITs) and other financial services in Beijing, which may decrease the VC inputs for innovation in the capital city.

Once the cointegration of venture capital and innovation is implemented, we establish a panel vector error correction model (VECM), which uses the two-step procedure from

[7] Wang (2004) and Xu and Zhang (2011) argue that the pattern of traditional manufacturing development in northeast China (including Jilin province) results in high consumption, pollution, and low value-added features in the pursuit of output growth; however, this imbalanced development in the economic structure and a strong dependence on heavy industry reduce local economic growth and restrain R&D input.

Table 5 DOLS long-run estimates: *Project* versus *Patent*—full sample

Variable	Dependent variable is *Patent*	Dependent variable is *Project*
Anhui	0.189 (14.564)**	0.652 (2.383)**
Beijing	−0.021 (−9.126)**	−0.076 (−0.142)
Chongqing	−12.498 (−3.485)**	−2.861 (−2.171)**
Fujian	0.139 (6.037)**	1.960 (3.192)**
Gansu	−1.151 (−8.666)**	−0.523 (−1.349)
Guangdong	−0.008 (−0.411)	−3.313 (−3.849)**
Guangxi	5.824 (41.223)**	2.554 (3.625)**
Guizhou	0.497 (4.817)**	−0.332 (−0.103)
Hebei	0.346 (13.229)**	9.509 (2.045)**
Henan	0.450 (24.427)**	−1.428 (−0.553)
Heilongjiang	−0.285 (−4.087)**	1.967 (1.376)
Hubei	0.014 (0.796)	0.169 (0.363)
Hunan	−0.013 (−0.102)	−3.767 (−2.663)**
Jilin	−0.224 (−0.680)	2.560 (4.950)**
Jiangsu	−0.001 (−0.176)	1.457 (9.131)**
Jiangxi	0.885 (7.695)**	0.021 (1.289)
Liaoning	0.159 (3.166)**	3.720 (3.260)**
Inner Mongolia	0.254 (2.062)**	3.189 (5.988)**
Ningxia	0.039 (0.588)	1.633 (1.676)*
Shandong	0.232 (8.716)**	−0.894 (−0.673)
Shanxi	0.625 (7.873)**	−3.177 (−7.946)**
Shaanxi	−0.046 (−2.538)**	−3.603 (−6.263)**
Shanghai	0.072 (6.947)**	2.147 (1.865)*
Sichuan	0.180 (40.604)**	−1.473 (−1.420)
Tianjin	0.050 (1.140)	0.765 (0.453)
Xinjiang	0.173 (3.742)**	5.271 (12.606)**
Yunnan	−0.222 (−0.826)	5.709 (3.123)**
Zhejiang	0.044 (3.405)**	1.322 (1.606)
Panel	0.189 (33.288)**	3.577 (6.010)**

t statistics in parenthesis.

** (*) Indicates statistical significance at the 5 % (10 %) level

Engle and Granger (1987), to examine both short-run and long-run causalities between venture capital and innovation. Using the combination of *Patent-Asset* as an example, the first step is to estimate Eqs. (5) and (6) in order to obtain the estimated residuals ε_{it} and v_{it} (error correction term; ECM hereafter). This allows for cointegrating the vectors of differing magnitudes between provinces, as well as the province (α) and time (δ) fixed effects.

$$Patent_{it} = \alpha_i + \delta_i t + \beta_i Asset_{it} + \varepsilon_{it}, \quad (5)$$

$$Asset_{it} = \varphi_i + \gamma_i t + \chi_i Patent_{it} + v_{it}. \quad (6)$$

The second step estimates the Granger causality model with a dynamic error correction as follows:

$$\Delta Patent_{it} = \theta_{1i} + \lambda_1 ECM_{it-1} + \sum\nolimits_k \theta_{11k} \Delta Patent_{it-k} + \sum\nolimits_k \theta_{12k} \Delta Asset_{it-k} + u_{1it} \quad (7)$$

$$\Delta Asset_{it} = \theta_{2i} + \lambda_2 ECM_{it-1} + \sum\nolimits_k \theta_{21k} \Delta Patent_{it-k} + \sum\nolimits_k \theta_{22k} \Delta Asset_{it-k} + u_{2it} \quad (8)$$

The sources of causation can be identified by testing for the significance of the coefficients of the dependent variables in Eqs. (7) and (8). First, for short-run causality, we can test $H_0{:}\theta_{12k} = 0$ for all k in Eq. (7) or $H_0{:}\theta_{21k} = 0$ for all k in Eq. (8). Next, the long-run causality can be tested by looking at the significance of the speed of adjustment λ, which is the coefficient of the error correction term. The significance of λ indicates the long-run relationship of the cointegrated process, and movements along this path can also be considered permanent. For long-run causality, we can test $H_0{:}\lambda_1 = 0$ in Eq. (7) or $H_0{:}\lambda_2 = 0$ in Eq. (8). We thus can carry out the joint test to check for strong causality or not, where variables usually facing the burden will adjust from a short-run to a long-run equilibrium under a shock to the system. Repeating Eqs. (5)–(8), we arrive at the VECM estimation for the combination of *Patent-Project*.

Table 6 shows the result of a panel causality test between venture capital and innovation. We find that no matter whether we analyze *Patent* or *Asset,* in the upper part of Table 6 the equations are insignificant at the 5 % level in the short run, implying a lack of short-run causalities; however, in the long run, we find both *Patent* and *Asset* equations are significant at the 5 % level, confirming the long-run bi-directional causal linkages between *Patent* and *Asset*. We hence move to the VECM estimation for the model of *Patent-Project*, whereby the bottom of Table 5 shows very similar results for the combination of *Patent-Asset*. Consequently, VC acts like a factor of innovative activity in China, as higher innovations also contribute to more VC inputs. Our evidence supports the conviction of previous studies' evidence for Granger causality between VC and patent applications in U.S. industries and European countries (Hirukawa and Ueda 2011; Geronikolaou and Papachristou 2012). Different from these previous theories, generally speaking, we focus on studying how VC affects innovation and vice versa via panel cointegration and causality tests.

Table 6 Panel causality tests—full sample

Dependent variable	Source of causation (*Patent* versus *Asset*)				
	Short run		Long run		
	$\Delta Patent$	$\Delta Asset$	λ	$\lambda/\Delta Patent$	$\lambda/\Delta Asset$
$\Delta Patent$	–	0.627	14.725**	–	6.565**
$\Delta Asset$	1.031	–	4.393**	8.923**	–
	Source of causation (*Patent* versus *Project*)				
	$\Delta Patent$	ΔProject	λ	$\lambda/\Delta Patent$	$\lambda/\Delta Project$
$\Delta Patent$	–	0.873	13.475**	–	22.852**
$\Delta Project$	1.783	–	3.231*	7.508**	–

** and * Indicate statistical significance at the 5 and 10 % levels, respectively. Because the parameters λ are the error-correction items to examine the long-run relationship between Patent and Asset/Project, examining the lag terms of other variables helps test for short-term causality. Therefore, the joint test with λ/ΔPatent, λ/ΔAsset, or λ/ΔProject can comprehensively examine the causality of two variables no matter in the short run or long run

3.3 Results of panel cointegration test and long-run estimate for the sub-samples

According to Tables 4 and 5, we acquire a few clues that the relationships between venture capital and innovation may depend on the disparity of the regions. The panel data encompass 28 provinces in China. Therefore, because of their remarkable differences in economic and social developments, the full sample is divided into three groups: eastern, central, and western regions, based on geographical location.[8]

We first confirm that the three series in each region exhibit a statistically significant I (1) process. Next, we turn to discuss whether the number of patent applications (*Patent*) is cointegrated with the amount of VC investment and VC investment projects (*Project*). Table 7 shows the results of Pedroni's (2004) panel cointegration test, in which most statistics significantly reject the null of no cointegration in the eastern and central regions for both *Patent-Asset* and *Patent-Project*. As a result, *Patent* has a long-run cointegrated relationship with both *Asset* and *Project*. Thus, it can be predicted that *Patent-Asset* and *Patent-Project* move together in the long run, no matter in the eastern or central region. Moreover, except for the panel variance, group-PP, and group-ADF statistic, most of our evidence shows that the western region accepts the null of no cointegration among series. We then use the panel DOLS estimation to determine the influence between *Patent* and *Asset* in the long run as well as *Patent* and *Project* in Table 7.

The results of Table 8 report only the panel estimators. In the eastern region, we find that increasing *Asset* and *Project* has a positive influence on *Patent*, as the panel coefficients are 1.112 and 0.934, respectively. *Patent* also presents a positive impact on *Asset* and *Project* that is statistically significant at the 5 % level. A very similar phenomenon is discovered in the central region, where the coefficients of *Patent* are statistically significant at the 5 % level and have a positive impact on *Asset* and *Project*, respectively. Furthermore, not only does *Asset* exhibit a statistically significant positive influence on *Patent*, but so does *Project*. Finally, in the western region we note that only *Asset* shows a positive impact on *Patent* that is statistically significant at the 10 % level. To conclude, the empirical result clearly indicates that just the eastern and central regions have a distinctly cointegrated relationship between venture capital and innovation.

Table 9 shows the result of VECM for a panel causality test. No matter whether the venture capital variables are substituted by *Asset* or *Project*, except for the short-run causality between *Patent* and *Asset* in the eastern region, we find that all equations are insignificant at the 5 % level in all regions, implying a lack of short-run causalities. Additionally, the significance of λ indicates a long-run relationship of the cointegrated process, and so movements along this path can be considered permanent in the eastern and central regions, meaning there is a long-run bidirectional causality between venture capital and innovation at the 5 % significant level. In the western region we see that there exists a one-way causal relationship running from VC variables to *Patent*.[9]

Given the above empirical results, both the eastern (including Beijing, Fujian, Guangdong, Hebei, Jiangsu, Liaoning, Shandong, Shanggai, Tianjin, and Zhejiang) and

[8] Eastern region: Beijing, Fujian, Guangdong, Hebei, Jiangsu, Liaoning, Shandong, Shanggai, Tianjin, and Zhejiang. Central region: Anhui, Henan, Heilongjiang, Hubei, Hunan, Jiangxi, Jilin, and Shanxi. Western region: Chongqing, Gansu, Guangxi, Guizhou, Neimenggu, Ningxia, Shaanxi, Sichuan, Xinjiang, and Yunnan.

[9] This may match the VC-first hypothesis proposed by Hirukawa and Ueda (2011), who define that VC always spurs innovation for new firms especially in the start-up stage.

Table 7 Panel cointegration tests—sub-samples

Models	*Patent* versus *Asset*	*Patent* versus *Project*
Eastern		
Panel variance	2.478**	−0.152
Panel ρ	−3.254**	−2.676**
Panel PP	−0.690	−2.397**
Panel ADF	−3.608**	−3.277**
Group ρ	0.763	0.487
Group PP	−1.522*	−3.458**
Group ADF	−3.852**	−5.026**
Central		
Panel variance	3.466**	2.375**
Panel ρ	−4.282**	−3.280**
Panel PP	1.109	−1.875**
Panel ADF	−0.706	−0.993
Group ρ	−4.695**	−5.279**
Group PP	−8.644**	−3.621**
Group ADF	−5.451**	−4.489**
Western		
Panel variance	1.363*	3.096**
Panel ρ	0.763	0.746
Panel PP	0.888	0.416
Panel ADF	1.258	−1.179
Group ρ	−0.113	−0.314
Group PP	−1.476*	0.179
Group ADF	−0.277	−1.737**

Statistics are asymptotically distributed as normal. The variance ratio test is right-sided, while the others are left-sided

** and * Indicate rejection of the null of no cointegration at the 5 and 10 % levels, respectively

Table 8 Panel parameters of DOLS estimates—sub-samples

Dependent variable is *Patent*	Dependent variable is *Asset*
Eastern	
1.112 (23.288)**	2.577 (12.090)**
Central	
0.834 (9.034)**	1.334 (3.094)**
Western	
0.034 (1.838)*	0.232 (0.213)
Dependent variable is *patent*	Dependent variable is *Project*
Eastern	
0.934 (6.098)**	1.309 (3.022)**
Central	
0.012 (3.343)**	2.884 (4.034)**
Western	
0.943 (1.225)	0.115 (0.923)

Same as Table 3

Table 9 Panel causality tests—sub-samples

Eastern					
	Short run		Long run		
	$\Delta patent$	$\Delta Asset$	λ	$\lambda/\Delta Patent$	$\lambda/\Delta Asset$
$\Delta Patent$	–	4.132**	8.877**	–	11.008**
$\Delta Asset$	5.065**	–	12.099**	10.763**	–
	$\Delta Patent$	$\Delta Project$	λ	$\lambda/\Delta Patent$	$\lambda/\Delta Project$
$\Delta Patent$	–	0.102	15.509**	–	17.095**
$\Delta Project$	1.114	–	9.098**	8.665**	–
Central					
	$\Delta Patent$	$\Delta Asset$	λ	$\lambda/\Delta Patent$	$\lambda/\Delta Asset$
$\Delta Patent$	–	0.223	13.088**	–	20.453**
$\Delta Asset$	0.776	–	9.343**	15.255**	–
	$\Delta Patent$	$\Delta Project$	λ	$\lambda/\Delta Patent$	$\lambda/\Delta Project$
$\Delta Patent$	–	0.112	23.098**	–	15.993**
$\Delta Project$	0.934	–	12.034**	10.223**	–
Western					
	$\Delta Patent$	$\Delta Asset$	λ	$\lambda/\Delta Patent$	$\lambda/\Delta Asset$
$\Delta Patent$	–	1.023	8.034**	–	9.034**
$\Delta Asset$	0.045	–	1.023	1.009	–
	$\Delta Patent$	$\Delta Project$	λ	$\lambda/\Delta Patent$	$\lambda/\Delta Project$
$\Delta Patent$	–	1.003	10.045**	–	12.093**
$\Delta Project$	0.023	–	2.003	1.056	–

Same as Table 5

central regions (including Anhui, Henan, Heilongjiang, Hubei, Hunan, Jiangxi, Jilin, and Shanxi) exhibit long-run bidirectional causality between venture capital and innovation, but not so in the western region. We offer potential reasons as follows. First, one knows that the promotion of VC is based on a perfect capital market in which innovation activity occurs rapidly; however, the western region lacks a sound foundation for a capital market. Compared to the eastern and central regions that offer a better quality of life and living environment, the western region faces a relatively disadvantageous environment. It thus lacks adequate incentives to attract talent and investment capital flows in Chongqing, Gansu, Guangxi, Guizhou, Neimenggu, Ningxia, Shaanxi, Sichuan, Xinjiang, and Yunnan. Finally, governments in the western region have not pushed for a lower capital gains tax and a supervised environment for VC development and the breeding of entrepreneurs (Arque-Catells 2012). In other words, the western region lacks a proper tax and financial policy to spur its VC industry.

In accordance with previous works, it is still difficult to conclude whether or not venture capital can promote enterprise innovation. For example, several studies challenge the opinion that VC can motivate innovation. Taking the interesting finding in Zucker et al. (1998), they report that VC imposes a positive effect only when investment is at a relative higher level in the bio-tech industry in the U.S.; if not, VC does not significantly improve innovation or even may impede it (Kortum and Lerner 2000). At the same time, as VC investment at the seed stage offers less capital input, the investee commonly cannot generate returns for investors, and investors thus may reduce their willingness to prompt innovation of invested enterprises (Croce et al. 2013). More adequate evidence is discovered by Graham et al. (2005), who complain VC managers may focus on short-sighted commercial interests and thus reduce R&D spending since innovative behavior can be considered to be just like burning money (Caselli et al. 2009).

Looking back at our samples, these seem to prove the reasonable explanations for the case of the western region. The statistics of our dataset show that the averages (total) of *Asset* in the eastern, central, and western regions are 1,395,226 (167,427,173), 238,003 (22,848,318), and 117,941 (14,152,915), respectively. Similarly, the averages (total) of *Project* are 42.5 (5100), 9.375 (900), and 6 (738) for the corresponding regions. Therefore, both *Asset* and *Project* present that the investment atmosphere in the western region is the lowest in China. When the scales of VC investment are relatively small, especially in the western and low-investment provinces after dividing the sample countries into different groups, the clear evidence shows that this may severely restrict the innovative abilities of invested enterprises. Accordingly, the scale effects are therefore supported in China.

4 Concluding remarks

By using the panel cointegration tests, this paper examines the co-movement and causal relationship between venture capital and innovation, employing data on 28 provinces in China from 2001 to 2012. Our results indicate that both venture capital variables (*Asset* and *Project*) and the proxy for innovation (*Patent*) are non-stationary and move together in the long run for the full sample. The panel DOLS estimations hence confirm positive long-run relationships between variables. Though short-run causalities are lacking among variables in accordance with our panel VECM estimation, evidence confirms the long-run bi-directional causal linkages between *Patent-Asset* and *Patent-Project* in the given sample of 28 provinces. Versus previous works that only focus on the one-way direction between venture capital and innovation, this paper provides a deeper investigation into this topic.

We also divide the provinces into three groups: eastern, central, and western regions. The results report that most statistics significantly reject the null of no cointegration in the eastern and central regions, while the western region accepts the null of no cointegration among series. The DOLS method also determines a positive influence from VC to *Patent* and vice versa. We again find long-run bidirectional causality between venture capital and innovation in both eastern and central regions.

Our evidence overall suggests a bidirectional causality and long-run relationship between venture capital and innovation in the full sample case, thus delivering some policy implications. The development of innovations in China should be based on more VC inputs. Moreover, China's government should establish a long-run innovation policy to accelerate the development of venture capital—for instance, by improving the legal protection of intellectual property to motivate more firm innovation and by establishing an effective communication platform for VC investors in order to increase the innovation level, especially in provinces located in the eastern and central regions. Because venture capital and innovation have an insignificant causality relationship in the western region, we suggest that western provinces can help introduce venture capital to promote innovation by setting up government venture capital funds and offering preferential tax policies to VC-backed firms. Such actions should lead to a more positive environment for venture capital in China.

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