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Female venture capitalists on boards and firm innovation in China

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ABSTRACT

This paper empirically examines the representation of female venture capitalists (VCs) on boards and how they exert substantial influence on firm innovation performance in China. We first identify a positive association between female VCs' board participation and firm innovation, implying that Chinese female VCs contribute to growing resource commitments and greater success in innovation through quality board services in portfolio firms. We then show that firms with female VC board directors exhibit a lower adverse effect of managerial myopia, capital market pressure, and product market competition on innovation activities. These results are robust to the use of instrumental variable (IV) estimations, subsamples, and alternative variable definitions.

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1. Introduction

Innovation is currently one of the enabling engines of economic growth in knowledge-based societies. The relationship between venture capitalists (VCs), as an essential form of venture financing, and technological innovation has been extensively studied in the literature (Bertoni and Tykvová 2015; Kortum and Lerner 2000). Prior studies on VC-backed firms and their performance have tended to concentrate on intensive monitoring by VCs, excellent VC expertise and board representation (Timmons and Bygrave 1986), low-level founder participation, superiority of independence with a limited time span (Barry et al. 1990; Lerner 1995). In terms of innovation, VCs contribute to the greater success of firms by supporting executives in innovative activities, creating a pro-innovation environment, implementing incentive plans that encourage innovation, anticipating technological advancement, identifying successful innovative projects in their project firms and even joining the board of target companies (Bernstein, Giroud, and Townsend 2016).

In recent years, China has experienced remarkable growth in both innovation and venture financing, with the domestic VC market booming (Guo and Jiang 2013). In fact, China has become the second-largest VC market in the world, with around 30% of global VC institutions investing in the country in 2018 (PitchBook, March 19 2019). However, China's VC industry differs significantly from that of the U.S. in terms of fund types, investment strategies, limited partner (LP) composition, investment stage, exit channels, and industries funded. Most studies on the impact of VCs on innovation have been conducted in the U.S. context, with little attention given to the different institutional settings and market conditions in China (Huang and Tian. 2020).

Previous literature has emphasized the importance of having VCs on corporate boards, and the drive to increase women's representation on boards has gained momentum due to the belief that women bring unique skills and perspectives (Chen, Leung, and Evans 2018; Chen, Ni, and Tong 2016; Farag and Mallin 2018; Godfrey et al. 2020). However, empirical evidence on the relationship between board gender diversity and firm outcomes

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is ambiguous. Studies by Ahern and Dittmar (2012) and Adams and Ferreira (2009) suggest a negative or neutral link between female board representation and corporate outcomes, while Gul, Srinidhi, and Ng (2011), Conyon and He (2017), Chen, Leung, and Evans (2018), and Mukarram, Ajmal, and Saeed (2018) report a positive association. The difference in legal and institutional frameworks plays a significant role in this relationship, as argued by Adams and Ferreira (2009), with the impact of female board representation on firm performance (measured by Tobin's q and ROA) being negative on average but turning positive in firms with weak governance systems. Despite the growing push for gender diversity, women still hold a small proportion of executive positions, with only 4.8% of female CEOs in Fortune 500 firms, and the situation is particularly severe in China.

China provides a unique institutional setting to assess the importance of board diversity and female board representation. China's rise in socioeconomic standing for women has allowed for increased board diversity and female board representation, though traditional norms still view men as more capable contributors to business and society (Huang, Lei, and Sun 2021). Despite empowerment through education and increased labor force participation, women remain underrepresented in leadership positions in Chinese companies. China's weak governance mechanisms which are due to several factors, including inactive institutional investors, limited equity holdings by executives, weak monitoring by outsiders, hindered markets for corporate control, and a weak legal infrastructure, present a significant obstacle to achieving gender equality (Allen, Qian, and Qian 2005; Berkman, Cole, and Fu 2014; Farag and Mallin 2019; Sun and Tong 2003). To address the 'glass ceiling' for women, female business leaders must work harder and create higher value than their male counterparts.

In this paper, we are interested in whether and how female VC investors affect companies' innovation performance through board representation in the Chinese context. Our analysis of listed manufacturing firms in China during 2005–2019 indicates that women VCs exert substantial influence on nurturing innovation through monitoring, advising and intervening in the boardroom. Consistent with our prediction, the adverse impacts of high managerial myopia, high capital market pressure and low product market competition on long-term innovation performance are less severe when female VC board directors are presented in the boardroom. Therefore, Chinese firms with female VC board directors devote more resources to R&D activities and generate more invention output from the innovation resource input. To mitigate endogeneity, we employ a propensity score matching algorithm, the instrumental variable approach and conduct a battery of robustness checks. Our findings remain consistent.

This study contributes to the existing literature in several ways. First, we add to the literature that investigates the VC industry in the Chinese context where shareholder protection and governance systems are relatively weak. Specifically, we have expanded on the unique contributions of our study by drawing attention to the role of female VC board members in Chinese VC-backed firms. Second, our work adds empirical evidence to the literature on the link between female board representation and firm performance. In line with previous research by Chen, Leung, and Evans (2018), we find a positive relationship between women's board participation and innovation. Our study differs from previous research by exploring alternative mechanisms through which female VC directors exert influence. Third, our study extends previous research which focuses on social performance and highlights the positive association between female leadership and gender diversity in the boardrooms of Chinese firms. By building upon this strand of research, our study further strengthens the understanding of the relationship between female leadership and firms' non-financial performance.

The organization of the paper is as follows. Section 2 presents a literature survey on the relationships between VC and innovation as well as female board directors and innovation, and develops research questions and hypotheses. Section 3 provides detailed sample data and methodology. In Sections 4 and 5, we propose the data analysis, hypothesis testing and robustness checks. Section 6 concludes and highlights the challenges and future research opportunities.

2. Literature review and hypothesis development

2.1. VC board representation, female board directors and innovation

Under the agency theory framework, which concerns a good internal institution for aligning managers' and shareholders' interests, VC investors actively participate on the board to help shape the strategic direction, assist

with operations, recruit talent in key positions, monitor management and influence firm innovation (Timmons and Bygrave 1986). A variety of evidence provided by the extant literature demonstrates that VC board presentation will improve organization performance by providing heterogeneous human and social capital, increased board independence and tougher monitoring (Celikyurt, Sevilir, and Shivdasani 2014; Hochberg 2012). For instance, Suchard (2009) shows that VCs use their networks and ties to employ outside directors with significant expertise and industry knowledge to enhance governance and performance in Australian portfolio firms. Van Den Berghe and Levrau (2002) focus on the role of VCs as a monitor of high-tech VC-backed companies and confirm that VCs play significant monitoring roles that are different from other types of shareholders and provide value-added consultancy through board activities.

A recent stream in the corporate governance literature starts to explore the relationship between board gender diversity and corporate performance with a focus on the impacts of female directors on firm performance (Conyon and He 2017; Hillman 2015; Post and Byron 2015). The first benefit brought by women's representation on boards is better decision-making quality and improved board effectiveness. The literature that studies such differences in decision-making styles and value judgements between male and female executives is based on the ethical reasoning provided by gender socialization theory (Chen, Ni, and Tong 2016). Men and women are socialized differently in terms of ethical judgement and behavior, thus resulting in different decision rules and board behaviors (Chen, Ni, and Tong 2016). This is because the education received by men and women is differently oriented, with women caring more about ethical issues and men being more aggressive and target-oriented (Post and Byron 2015). Gender differences in ethical judgement and behavior also lead to cognitive differences between men and women in core values, risk attitudes, backgrounds and perspectives (Conyon and He 2017).

In addition to adding diverse perspectives to the boardroom, female boards of directors with distinct human and social capital can also bring in a more cooperative decision-making process. Women directors on boards can generate a critical evaluation of alternative solutions to sensitive issues, elicit innovative insights from team members and encourage collaboration within a group (Terjesen, Sealy, and Singh 2009). Indeed, female members who possess better communication and interpersonal skills are considered to be better informed by managers and, hence, make better decisions (Jelinek and Adler 1988). Better decision making will then transform into better firm-level performance. Conyon and He (2017) compiled a sample including 3,000 U.S. companies from 2007 to 2014 and find a positive correlation between the fractions of women board members and accounting performance.

In terms of innovation, findings from a resource utilization perspective suggest that companies with more gender-diverse boards and effective monitoring are more likely to concentrate resources in innovative projects and achieve greater innovation success from their R&D investments (Chen, Leung, and Evans 2018). Therefore, boardroom gender diversity, which reflects a gender-diversified customer base and labor pool, is considered by the literature to be a competitive advantage that fosters the search for innovative ideas, enhances collaboration within a group, improves decision-making quality and strategic control, and promotes innovation (Erhardt, Werbel, and Shrader 2003; Post and Byron 2015).

Whereas a gender-diverse board can improve decision-making quality, it may also improve board monitoring effectiveness and information disclosure. Empirically, researchers find that female representation on boards affects the level of management accountability and board monitoring through higher attendance and more board meetings (Adams and Ferreira 2009; Gul, Srinidhi, and Ng 2011). Compared with their male counterparts, female directors are generally more diligent monitors (Chen, Ni, and Tong 2016).

In particular, in institutional settings with weak governance and investor protection, such as the Chinese market, a board with female directors may serve as an additional instrument for corporate governance to enhance monitoring of top management and increase performance. Because over monitoring may negatively affect firm value in firms with high shareholder rights, gender-diverse boards will be mostly favorable for companies with weak governance and investor protections (Adams and Ferreira 2009; Gul, Srinidhi, and Ng 2011). Therefore, the addition of female VC directors on boards may also induce positive effects on firm innovation. We expect to observe a positive correlation between female VCs board representation and firm innovation. Thus, we hypothesize as follows:

H1: The participation of female VC directors on boards are positively associated with firm innovation in China.

2.2. Female board directors, managerial myopia, and innovation

Whereas the extant literature validates the influence of female board representation on innovation and performance, the specific mechanisms underlying these different findings have not been examined. In this study, we are also interested in investigating the potential channels through which female VC directors exert influence. The first channel we examine relates to managerial myopia, where managers may display a reluctance to invest in risky R&D projects, consequently hindering corporate innovation (Chang et al. 2015; Wahal and McConnell 2000). However, the presence of female VC directors in the boardroom can potentially mitigate such corporate short-termism, serving as a crucial factor in promoting long-term innovation.

Empirical studies examining managerial myopia have consistently highlighted the presence of constraints that limit managers' ability to prioritize long-term objectives (e.g. Chang et al. 2015). These constraints which stem from external sources, such as the fear of losing jobs, short-term performance-based compensation, capital market pressure and pressure from impatient shareholders who value short-run profits, restrain managers from maximizing firms' long-term value (Bolton, Scheinkman, and Xiong 2006; Fudenberg and Tirole 1995; Noe and Rebello 1997).

The focus on the short-term profits of myopic managers negatively affects innovation performance. For instance, a survey of CFOs of U.S. firms confirms this negative influence as they expressed their willingness to achieve targeted short-run profits over long-run objectives (Graham, Harvey, and Rajgopal 2005). In fact, 80% of CFOs who participated in the survey are willing to manage long-term expenditures, such as R&D expenses, to achieve a targeted accounting benchmark. Similarly, Brochet, Loumioti, and Serafeim (2015) also suggest that myopic firms engage in real earnings management in terms of lower discretionary R&D and advertising expenses. Other studies have also reported similar findings, indicating that managers reduce R&D spending in exchange for higher reported earnings in the current period (e.g. Baber, Fairfield, and Haggard 1991; Bens et al. 2003; Osma and Young 2009).

In contrast, the prior literature on boardroom gender diversity has shown that gender is an important factor when shaping individuals' attitudes towards investment decisions and long-term organization strategies. The increasing number of studies exploring the relationship between gender diversity and board behavior underscores the growing recognition of the positive effects that female directors have on shaping organizational outcomes and fostering a more inclusive and effective governance environment (Adams and Ferreira 2009; Chen, Leung, and Evans 2018; Chen, Ni, and Tong 2016; Conyon and He 2017). Unlike their male counterparts, who are often characterized as assertive and task-oriented (Post and Byron 2015), female directors tend to exhibit more patient and long-term oriented perspectives.

Drawing from the existing literature on board gender diversity and managerial myopia, studies have shown that the presence of women in the boardroom can help mitigate myopic investment behavior (e.g. Liu, Wei, and Xie 2016). Gender-diverse boards are more inclined to prioritize sustainability and drive long-term performance improvements (Chen, Ni, and Tong 2016). In particular, research on female top executives and earnings management finds that female CFOs are less likely to reduce discretionary expenditures such as R&D as a way to improve earnings levels in the current period and, thus, are better able to avoid myopic decisions (Liu, Wei, and Xie 2016).

Building upon the literature on boardroom gender diversity and managerial myopia and innovation, we predict that the participation of female VC directors can attenuate the adverse impact of managerial myopia on long-term innovation. By leveraging their diverse perspectives and decision-making approaches, female VC directors contribute to fostering an environment that values and supports long-term innovative initiatives. Thus, we hypothesize as follows:

H2: The negative impact of managerial myopia on innovation is weakened by the participation of female VC board members in China.

2.3. Female board directors, capital market pressure, and innovation

The second mechanism through which women VC board directors promote innovation is related to the capital market pressure. In this section, we delve into the intuition behind the negative relationship between innovation and capital market pressure, as measured by analyst coverage. The prior literature has identified various sources of corporate short-termism, including compensational pressure, investor short-termism, and capital market pressure (Fudenberg and Tirole 1995). Analyst coverage as a primary form of external governance can result in managers pursing short-term profit maximizing projects over long-term projects that generate higher total cash flow (Bhojraj and Libby 2005), and negatively impacts corporate innovation due to the exacerbated managerial myopia it creates (He and Tian 2013). This is because the job of analysts for forecasting near-term earnings and commenting on stock performance makes them less failure tolerant and more short-term focus, hence, impeding firm innovation.

Research has demonstrated that gender-diverse boards improve informativeness of stock prices through greater public disclosure (Gul, Srinidhi, and Ng 2011). Managers on gender-diverse boards are encouraged to issue more voluntary disclosures and high-quality public reports. This effect is more pronounced in firms with weak external governance, such as those with limited analyst coverage. In such cases, female board participation adds an additional layer of governance, contributing to improved oversight and decision-making processes within the firm (Evgeniou and Vermaelen 2017). Combing the literature of stock market pressure, board gender diversity and innovation, we speculate that the negative relationship between analyst coverage and innovation is weakened by the representation of female VC board directors which helps counteract the negative effects of capital market pressure on firm innovation. Thus, we hypothesize as follows:

H3: The negative impact of analyst coverage on innovation is weakened by the participation of female VC board members in China.

2.4. Female board directors, product market competition, and innovation

In this section, we investigate the third channel through which women board VC directors promote innovative activities in project firms. Previous literature postulates that managers who have a disposition to a quiet life are unwilling to engage in innovative and inventive activities (Bertrand and Mullainathan 2003). However, gender diversified boards play a crucial role in providing a failure-tolerant environment for managers, which serves as a key determinant for promoting greater innovation, as highlighted by Manso (2011). Moreover, female directors' presence reduces managerial slack, myopic investment behaviors and redirects resources to innovative and value-enhancing projects by improved monitoring of the board activities (Bertrand and Mullainathan 2003). Specially, this effect is more prominent in industries characterized by a low level of competition. As firms in highly competitive industries face higher risks for survival, managers in these industries are under greater pressure for meeting profit targets (Chen, Leung, and Evans 2018). Therefore, the issues arising from managerial shirking and the need for enhanced supervision from female board directors are less prevalent in firms operating in highly competitive environments.

Combining the literature on product market competition and female board representation and innovation, we predict that the participation of female VC directors will lessen the adverse influence of managerial slack due to low production market competition pressure on long-term innovation. Thus, we hypothesize as follows:

H4: The positive association between female VC board directors and project firm innovation is stronger in firms with low product competition level in China.

3. Data and methodologies

3.1. Data and sample

The data in this study are obtained from various commercial and public sources commonly used in academic research (e.g. Zero2IPO, WIND and CSMAR databases). We use the data of all manufacturing firms listed on

both the Shanghai and Shenzhen Stock Exchanges from 2005 to 2019. In total, a dataset of 2600 listed manufacturing firms during the 2005–2019 observation years is initially drawn from databases. To construct our sample of VC-backed firms, we screen out firms that obtained their initial round of investment after 2016 to capture the influence of VC board directors on innovation after VC investment as data on VC deals becomes available after several years. We then screen out companies with missing financial data, and the dataset is left with 670 VC-backed companies that received the first round of VC investment between 2005 and 2016 and with firm accounting data from 2005–2019. Consistent with Celikyurt, Sevilir, and Shivdasani (2014) who contends that VCs sit on boards of directors long after their IPOs, we find that approximately 55 per cent of these firms in our sample (396 firms) have at least one VC director on the board during the entire examination period, and 84 firms have female VC directors on their boards.

Demographic information on VC investors for each VC-backed company in the dataset, including the total number of investors, name, gender, age, educational background and number of years on the board (i.e. director tenure), is manually extracted from the 'Board of Directors, Supervisory Board of Directors and Top Management' section of the IPO prospectuses and VC investors' and investee companies' websites. Data on VC investments for each listed manufacturing firm, including the fund name, the type of VC, investment amount, number of VC investors in each deal, total amount of VC funds gained by the company and the number of financing rounds, are obtained from the WIND and Zero2IPO databases. The dataset of VC deal information is then merged with IPO firm list.

Accounting and other firm-level information, such as leverage ratio, total sales, return on assets (ROA), industry and founding year, are drawn from the CSMAR database. Patent data are obtained from the CSMAR patent database, which provides complete patent data on the number of patent applications, the number of patent applications that are finally granted, the number of patents acquired from other companies, the number of patents terminated for both the parent company and subsidiaries, and the application location of the patents. Data collected from various sources ensure that our dataset offers an extensive representation of the VC-backed companies in the manufacturing sector. Data from different databases are then manually matched and checked according to their official registered details (i.e. name, tax registration information, address, and stakeholders).

The reason for starting from 2005 is that a significant transformation occurred in the Chinese VC market. Venture funds skyrocketed from US$699 million in 2004 to US$4.067 billion because of a series of regulations and policy changes on private equity investment issued by the government in 2004 and 2005 (Guo and Jiang 2013). Moreover, according to the Guidelines for Industry Classification of Listed Companies issued by the China Securities Regulatory Commission (CSRC) in 2012, the listed firms in China are classified into 19 major industries: Agriculture, Forestry, Animal Husbandry, and Fisheries (5 subsectors), Mining (7 subsectors), Manufacturing (31 subsectors), Electricity, Heat, Gas, and Water Production and Supply (3 subsectors), Construction (4 subsectors), Wholesale and Retail (2 subsectors), Trade Transportation, Warehousing, and Postal Services (8 subsectors), Accommodation and Catering Services (2 subsectors), Information Transmission, Software, and Information Technology Services (3 subsectors) Finance (4 subsectors), Real Estate (1 subsector), Leasing and Business Services (2 subsectors), Scientific Research and Technical Services (3 subsectors), Water Conservation, Environmental Protection, and Public Facilities Management (3 subsectors), Residential Services, Repair, and Other Services (3 subsectors), Education (1 subsector), Health and Social Work (2 subsectors), Culture, Sports, and Entertainment (5 subsectors), and Comprehensive (1 subsector). Notably, the majority of the listed firms operate within the manufacturing industry and are the most active in investing in R&D programs and generating inventions and patents (Liu and Buck 2007).

Table 1 presents the industry distribution and the initial round investment year of the sampled VC director firms and firms with female VC directors. For firms with VC directors on the board, 26 subsectors exist under the manufacturing category, among which 6 are classified as high-tech manufacturing industries according to the high-tech industry (Manufacturing Industry) classifications (2013)[1] issued by the Chinese State Statistical Bureau (SSB) and as used by Liu and Buck (2007).

As shown in Panel A of Table 1, firms with VC directors are concentrated in five major industries, i.e. computer, communication and other electronic, special equipment manufacturing, electrical machinery and equipment manufacturing, chemical materials and products manufacturing, and pharmaceutical manufacturing, which comprise 58.8% of all VC-backed firms with VC board directors in our sample. Similarly, firms with

Table 1. Industry distribution and investment year of VC director and female VC director firms.

Panel A: Industry distribution	Total Freq.	Female Freq.	Total %	Female %
Agricultural and Food Processing	6	0	1.5%	0.0%
Automobile Manufacturing	17	3	4.3%	3.6%
Chemical Fiber Manufacturing	1	0	0.3%	0.0%
Chemical Materials and Products Manufacturing	45	7	11.4%	8.3%
Comprehensive Utilization of Waste Resources	1	1	0.3%	1.2%
Computer, Communication and Other electronic Equipment Manufacturing	72	15	18.2%	17.9%
Culture and Education, Arts and Crafts, Sports and Entertainment Products Manufacturing	4	1	1.0%	1.2%
Electrical Machinery and Equipment Manufacturing	37	9	9.3%	10.7%
Ferrous Metal Smelting and Calendering	1	0	0.3%	0.0%
Food Manufacturing	4	1	1.0%	1.2%
Furniture Manufacturing	6	3	1.5%	3.6%
General Equipment Manufacturing	28	2	7.1%	2.4%
Instrument Manufacturing	11	5	2.8%	6.0%
Leather, Fur, Feather Products and Shoemaking	1	1	0.3%	1.2%
Metal Products	14	1	3.5%	1.2%
Non Metallic Mineral Products	18	2	4.5%	2.4%
Nonferrous Metal Smelting and Calendering	9	2	2.3%	2.4%
Other Manufacturing	3	1	0.8%	1.2%
Paper and Paper Products	2	1	0.5%	1.2%
Pharmaceutical Manufacturing	33	8	8.3%	9.5%
Railway, Shipping, Aerospace and Other Transportation Equipment Manufacturing	7	1	1.8%	1.2%
Rubber and Plastic Products Manufacturing	17	4	4.3%	4.8%
Special Equipment Manufacturing	46	10	11.6%	11.9%
Textile	2	1	0.5%	1.2%
Textile and Clothing	10	5	2.5%	6.0%
Wine, Beverage and Refined Tea Manufacturing	1	0	0.3%	0.0%
Total	396	84	100%	100%
Panel B: Initial round investment year				
2005	8	1	2.0%	1.2%
2006	8	1	2.0%	1.2%
2007	56	15	14.1%	17.9%
2008	41	6	10.4%	7.1%
2009	28	6	7.1%	7.1%
2010	75	11	18.9%	13.1%
2011	94	26	23.7%	31.0%
2012	38	9	9.6%	10.7%
2013	20	2	5.1%	2.4%
2014	15	4	3.8%	4.8%
2015	12	3	3.0%	3.6%
2016	1	0	0.3%	0.0%
Total	396	84	100%	100%

female VC directors on board are concentrated in computer, communication and other electronic, special equipment manufacturing, electrical machinery and equipment manufacturing, pharmaceutical manufacturing, and chemical materials and products manufacturing (58.3%).

Panel B of Table 1 shows the number of firms that received their first round of VC investments in each year from 2005 to 2016. Firms with female VC directors receives first round of investment in 2005–2015. In accordance with the literature, most of the sampled firms obtained their first round of VC investments after 2006, when the VC industry was experiencing a dramatic transformation (Guo and Jiang 2013). The total number of IPO cases dropped significantly from 2012–2014 as IPO was strictly regulated and restricted before 2015 (Guo and Jiang 2013; Huang and Tian 2020). Specially, in the August of 2010 the CSRC issued 'Guiding Opinions on Deepening the Reform of New Share Issuance System' to better regulate China's security market.

3.2. Measures of variables

3.2.1. Measuring innovation

We are interested in the innovation activities of the firms in this study that receive VC investments. We observe both innovation input measures, such as R&D intensity and output measures, including the number of patents.

First, R&D investment as a measurement of innovation effort reflects a firm's innovation route and shapes its future development. The innovation literature provides several measures for a firm's resource input into innovation activities, such as the natural logarithm of R&D expenditures (Chen, Leung, and Evans 2018), the number of R&D employees (Kamien and Schwartz 1975) and R&D expenditures over sales or other firm size variables, such as R&D intensity (Guo and Jiang 2013; Hitt et al. 1991; Lee and O'neill 2003). These measures are easy to understand and can be easily obtained from financial reports. Therefore, in this study, we measure firms' resource input into innovation activities by the ratio of R&D expenditures to total sales, which is denoted as *R&D ratio*, following the literature.

However, one disadvantage associated with this input-oriented measure is its failure to capture the success of innovation activities. Hence, adding an output-related measure of innovation, such as patent count, to reflect the effectiveness of the company's resource utilization of its innovation input is important (Chen, Leung, and Evans 2018). Following He and Tian (2013), we measure the innovation output by the number of all patent applications of a given firm in a given year that are eventually granted in natural logarithm format.

3.2.2. Measuring explanatory variables

The impact arising from the involvement of women VC directors on boards is the focus of this study. In this study, we follow Adams and Ferreira (2009) to use the *female VC board director* dummy variable as a proxy for female VC board representation. This binary variable equal 1 if there is at least one female VC director present on the board. We use the *short_invest ratio*, which captures short-term investments (including tradable financial assets, available-for-sale securities and held-to-maturity securities) scaled by total assets. This measure, adapted from that in Brochet, Loumioti, and Serafeim (2015), allows us to further explore the relationship between managerial myopia and innovation. Subsequently, we interact the *female VC board director* with the *short_invest ratio* to investigate the moderating effect of female VC board representation on managerial myopia and innovation. Last, *analyst_coverage* proxied as the number of analysts tracking the firm is used to measure management pressure from the external stock market.

3.2.3. Measuring control variables

The control variables used in this study are comprised of firm-specific variables and variables of board characteristics and ownership structure concerning the existing corporate governance and innovation literature (Chen, Leung, and Evans 2018; Guo, Guo, and Jiang 2016). Firm characteristics that are determinants of innovation and include *leverage*, *total assets*, *sales*, *intangible assets,* and *ROA* (detailed definitions of the variables are provided in the Appendix 1). *Leverage*, which reflects the firm's financial condition and variance in its ability to access the external capital market, is measured by the ratio of total debt to total assets. VCs tend to invest in low-leveraged firms because their liquidation values are higher, thus making them easier to exit (Guo and Jiang 2013). *Total assets* are believed to have a positive effect on firm patenting activities because large firms may benefit from economies of scale in patent production and have more resources to cover the fixed costs of setting up a legal unit that deals with intellectual property (IP)-related matters (Hall and Ziedonis 2001; Lerner 1995). We use the log value of firm total assets in this study.

We also control for *sales*, which is highly related to R&D expenditures (Himmelberg and Petersen 1994) and, hence, can be used to better evaluate R&D expenditures across firms (Grabowski 1968). *Intangible assets* are measured by the ratio of intangible assets over total assets in a given year. *ROA* reflects firms' profitability, which affects both companies' financial and investors' investment decisions (Bennouri et al. 2018). *Board size* is an indicator of board characteristics, which is measured by the natural logarithm of the number of directors on the board. Moreover, we follow Chen, Leung, and Evans (2018) to control for board independence to differentiate the possible effects brought by outside directors in the boardroom between those brought by female VC directors. *Out_ratio* is the percentage of independent directors on the board.

3.3. Descriptive statistics

Table 2 reports the descriptive statistics of the variables used in this study based on firm-year observations. On average, companies with VC board director in our sample have *R&D ratio* of 0.049, log value of patent of 1.13,

Table 2. Descriptive statistics.

Variables	Obs.	Mean	SD	Min.	Median	Max.
Female VC board director	2614	0.816	0.387	0	1	1
R&D ratio	2614	0.049	0.034	0	0.04	0.179
Patent	2614	1.13	1.598	0	0	5.525
Leverage	2614	0.356	0.173	0.046	0.348	0.777
Total assets	2614	20.73	0.959	18.539	20.664	23.893
Sales	2614	20.267	0.988	18.273	20.171	23.584
Intangible assets	2614	0.046	0.033	0	0.04	0.179
Out_ratio	2614	0.288	0.154	0	0.333	0.556
Board size	2614	1.79	0.877	0	2.197	2.565
ROA	2614	0.089	0.061	−0.023	0.079	0.328

Notes: This table reports the summary statistics for Chinese manufacturing listed companies with VC board directors from 2005 to 2019. The observational unit is a listed manufacturing company with at least one VC director on the board in China. Variables are defined in Appendix 1.

leverage ratio of 0.356, total assets of 20.73, total sales of 20.267, ratio of outside board directors of 0.288, board size of 1.79, a ratio of intangible assets of 0.046 and ROA of 0.089. The average *female VC board director* for firms with VC directors on the board is 0.816, suggesting that, on average, firms with VC directors on their board tend to have a higher proportion of women directors compared to firms without VC directors on their board. The log value of patent applications ranges from 0 to 5.252 with a standard deviation of 1.598 for *patent*. The large range and significant standard deviation suggest that innovations across firms are inconsistent over time. There is considerable variation in the number of patent applications across different firms and across different years within the same firm.

3.4. Empirical models

We estimate the impacts of women VC directors' board representation on the firm's innovation activities through the following empirical model specifications with reference to the innovation literature:

$$\begin{aligned} Innovation_{i,t} = {} & \alpha_0 + \alpha_1 Women VC\ board\ director_{i,t} + \alpha_3 Moderator_{i,t} \\ & + \alpha_4 Women VC\ board\ director_{i,t} * Moderator_{i,t} + \alpha_5 Z_{i,t-1} \\ & + \alpha_6 year_t + \alpha_7 industry_i + \varepsilon_{i,t} \end{aligned} \quad (1)$$

where i denotes a particular company, t is time, and $Innovation_{i,t}$ are dependent variables for measuring the output- and input-related innovation performance of company i at time t. The key moderators are *short_investratio* and *analyst_coverage* respectively, both of them have been defined in the previous sections. $Z_{i,t-1}$ is a vector of innovation-related firm characteristics (control variables) that are widely used in the literature (Chen, Leung, and Evans 2018; Guo, Guo, and Jiang 2016), including *leverage*, *total assets*, *sales*, *out_ratio*, *board size*, *intangible assets* and *ROA* (detailed definitions of the variables are provided in the Appendix 1). Industry and year fixed effects are captured by $industry_i$ and $year_t$ using the CSRC's 2012 guidelines for the industry classification of listed companies.

3.5. Mitigating endogeneity

The primary concerns when estimating the impacts of women VCs on corporate innovation are the identification problems derived from selection biases and omitted variables. In particular, the representation of women VC directors on boards is likely to be endogenous. Moreover, the baseline results could be biased by the unobserved variables correlated with both our independent and dependent variables. For example, the injection of VC funding may be determined by an excellent top-management team and that the company may be more inventive and innovative at the same time (Bertoni and Tykvová 2015). Furthermore, reverse causality appears when female VC directors personally select more innovative companies (Farrell and Hersch 2005), or better-performing companies are more active in search of female VC board directors (Chen, Leung, and Evans 2018).

However, these concerns can be mitigated through a propensity score matching (PSM) method and a two-stage estimation process using an IV of cultivated land per capita (*landpp*).

To test our hypotheses, the PSM algorithm is used to match firms with female VC board directors with firms without female VC board directors based on a number of criteria that affect the likelihood of a company being monitored by female VC board directors and its innovation potential. The control group is consisted of firm-year observations with women board VC directors (women VC directors only or women and men VC directors). The control group includes observations of firms with men VC directors. We focus on corporate innovation activities when designing the algorithm and construct two groups of firms based on the propensity score, which is the predicted likelihood of a company having women VC board members. The control groups of firms are then constructed on the basis of the leverage, total assets, public age, firm age, intangible assets, board size, and ROA firm characteristics. These covariates used in the logit model ensure that the firms in the treated and control groups have similar characteristics, which may influence the likelihood of having women VC board directors and their innovation potential.

We utilize a kernel matching approach to identify firms in control, which have the closest propensity scores compared with their counterparts in the treated group. The differences in innovation variables are both economically and statistically significant.[2] In other words, firms in both treatment groups have higher mean values of *R&D ratio* and *patent* than their counterparts in the PSM matched sample. Moreover, we keep the difference in the propensity score between the treated and control firms at the minimum such that the matched pair becomes indistinguishable. Therefore, the results of our estimation on firm innovation performance can be interpreted based on our treatment effect of having women VC directors on boards.

4. Empirical analysis and discussion

4.1. Baseline results

In the regression analysis, we first examine the relationship between the participation of women VC directors on boards and corporate innovation by regressing firm innovation on *female VC board director* while controlling for firm characteristics and other factors using a PSM sample. We lag one year for the control variables to mitigate the issues related to potential simultaneity. We also include year and industry dummies in our regressions to control the yearly fixed effects and the effects of external economic shocks and unobservable industry factors. To test **H1**, we use the pooled OLS model to estimate Equation (1).

In Table 3, Models (1)–(3) show a positive and statistically significant relationship between women's VC representation in the boardroom and innovation measures by *R&D ratio*, patent and invention applications. For example, the coefficient of *female VC board* directors in models (1) in Table 3 is 0.020 ($p < 0.01$), suggesting that firms' *R&D ratio* are 2% higher when female VC board directors are presented on boards. Given the mean values of 0.049 for *R&D ratio*, the impacts of female VC board directors are both economically and statistically significant. Moreover, Models (2) and (3) of Table 3 indicate that the number of patent and inventions applications of firms with women VC board directors is 0.598 and 0.381 higher than those of firms without female VC board directors, respectively. Correlations between the control variables and the dependent variables are consistent with those estimated in the literature. For instance, the log value of total assets is positively and significantly correlated with patent and invention applications, implying that larger firms enjoy higher innovation productivity. A higher profitability measured by ROA will also contribute to higher *R&D ratio*, which is consistent with the findings in Balsmeier, Buchwald, and Stiebale (2014).

Overall, these findings confirm our hypothesis of the positive relationship between female VC directors' board representation and corporate innovation activities. This finding is consistent with the result found by Conyon and He (2017), they compiled a sample including 3,000 U.S. companies with firm data from 2007 to 2014, and they find a positive correlation between the fractions of women board members and firm performance.

4.2. Female VC directors, managerial myopia and innovation

To further examine our results regarding the relationship between managerial myopia and innovation, as well as the moderating effect of female VC board representation, we conduct regression analysis to test H2.

Table 3. Female VC board directors and innovation (PSM sample).

	R&D ratio	Patent
Variables	(1)	(2)
Female VC board director	0.020***	0.598***
	(5.149)	(6.675)
Leverage	−0.004	−1.140***
	(−0.682)	(−4.082)
Total assets	0.020***	0.569***
	(7.734)	(4.779)
Sales	−0.025***	−0.170*
	(−11.006)	(−1.714)
Intangible assets	−0.072**	−1.910*
	(−2.283)	(−1.789)
Out_ratio	−0.026**	1.432***
	(−1.996)	(3.032)
Board size	0.001	0.043
	(0.231)	(0.526)
ROA	0.130***	−2.975***
	(5.867)	(−4.059)
Constant	0.096***	−7.224***
	(3.841)	(−6.033)
Year	Yes	Yes
Industry	Yes	Yes
No. of obs.	1439	1416
R^2	0.376	0.496

Notes: OLS estimation results using PSM-matched sample. Dependent variables: *R&D ratio*, R&D expenditure divided by total sales; *Patent*, the log value of the total number of patent application. Independent variable: *Female VC board director*, a dummy variable equals to one if a firm has at least one female VC director on its board and zero if otherwise. *Leverage*, the sum of short-term and long-term debts divided by total assets; *Total assets*, the log value of firm's total assets; *Sales*, the log value of total sales; *Intangible assets*, total assets minus property, plant and equipment divided by total assets; *Out_ratio*, the fraction of independent board directors; *Board size*, the log value of the number of board directors; *ROA*, the earnings before interest, taxes, depreciation, and amortization divided by total assets. All regressions include yearly and industry fixed effects. The robust t-statistics are reported in parentheses. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$.

Specifically, we regress innovation on the *short_invest ratio* and include the interaction term of *female VC board director*∗*short_invest ratio*. The results are reported in Table 4.

In Column (2) and (4) of Table 4, we observed significantly negative coefficient estimates for the *short_invest ratio*, indicating that managerial myopia can negatively affect innovation. Notably, the multiplicative interaction terms are significantly positive when we interact the *short_invest ratio* with *female VC board director* as shown in Column (2) and (4) (0.477, $p < 0.01$, and 13.541, $p < 0.05$). This implies that the presence of women VC directors on the board weakens the negative relationship between managerial myopia and innovation. In terms of firm characteristics controls, *sales* and *intangible assets* are negatively correlated with innovation input while positively linked to innovation output. Consistent with literature, firm total assets and *ROA* are positively associated with innovation activities. In terms of firm characteristics controls, *sales* and *intangible assets* are negatively correlated with innovation input while positively linked to innovation output. Consistent with literature, firm total assets and *ROA* are positively associated with innovation activities.

The results suggest that the negative relation between managerial myopia and innovation is weaker for firms with women VC directors on their boards. This finding is supported by empirical analysis worldwide. According to Ahern and Dittmar (2012), Bennouri et al. (2018), Conyon and He (2017), and Terjesen, Aguilera, and Lorenz (2015), gender diversity in the boardroom has been promoted as an effective mechanism to ensure good functioning of boards. Studies have shown that women differ from men in terms of their value judgments, risk

Table 4. Managerial myopia, female VC board directors and innovation.

	R&D ratio		Patent	
Variables	(1)	(2)	(3)	(4)
Short_invest ratio	−0.020	−0.495***	−0.260	−13.815**
	(−0.857)	(−2.767)	(−0.290)	(−2.060)
Female VC board director∗short_invest ratio		0.477***		13.541**
		(2.649)		(2.003)
Leverage	−0.003	−0.003	−1.010***	−1.130***
	(−0.656)	(−0.678)	(−5.024)	(−6.020)
Total assets	0.016***	0.016***	0.537***	0.619***
	(7.467)	(7.527)	(6.246)	(7.668)
Sales	−0.022***	−0.022***	0.012	−0.040
	(−12.019)	(−12.067)	(0.158)	(−0.573)
Intangible assets	−0.015	−0.015	1.892***	2.163***
	(−1.537)	(−1.579)	(4.842)	(5.531)
Out_ratio	0.003*	0.003*	0.287***	0.331***
	(1.697)	(1.651)	(4.399)	(5.155)
ROA	0.088***	0.089***	−1.798***	−1.382**
	(5.624)	(5.712)	(−3.084)	(−2.363)
Constant	0.142***	0.141***	−10.107***	−10.578***
	(6.777)	(6.720)	(−10.774)	(−12.733)
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
No. of obs.	2221	2221	2221	2221
R^2	0.359	0.360	0.479	0.454

Notes: OLS estimation results. Dependent variables: *R&D ratio*, R&D expenditure divided by total sales; *Patent*, the log value of the total number of patent applications. Independent variables: *Short_invest ratio*, the short investment divided by total assets; *Female VC board director* short_invest ratio*, an interaction term between *female VC board director* and *short_invest ratio*. *Leverage*, the sum of short-term and long-term debts divided by total assets; *Total assets*, the log value of firm's total assets; *Sales*, the log value of total sales; *Out_ratio*, the fraction of independent board directors; *ROA*, the earnings before interest, taxes, depreciation, and amortization divided by total assets. All regressions include yearly and industry fixed effects. The robust t-statistics are reported in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

attitudes, and management styles, which makes them valuable assets to corporate boards (Chen, Ni, and Tong 2016). Overall, our results support our hypothesis that the representation of female VC directors weakens the adverse effect of managerial myopia on innovation.

4.3. Female VC directors, capital market pressure and innovation

The pressure hypothesis suggests that external stock market pressure, as reflected by analyst coverage, may hinder firms' innovative activities. However, the presence of female directors on boards helps alleviate such negative effects. To test the pressure hypothesis, we regress innovation on the *analyst_coverage* and the interaction term of *female VC board director∗analyst_coverage*. The results are presented in Table 5. As shown in Column (2) and (4) of Table 5, the coefficient estimates of the interaction term, *female VC board director∗analyst_coverage*, are both economically and statistically significant for all measures of innovation (0.129, $p < 0.01$ and 0.052, $p < 0.01$). This means firms followed by external analysts with female VC board directors have 5.2% higher patent applications compared with those without female VC board directors.

By encouraging managers to provide more voluntary disclosures and producing high-quality public reports, female VC directors enhance firm transparency, governance, and provides comprehensive information to uninformed investors. This effect is particularly prominent in firms with weak external governance, such as those with limited analyst coverage. Consequently, female VC board participation leads to improved oversight and decision-making processes within the firm and ultimately spur innovation (Evgeniou and Vermaelen 2017). This result is different from studies conducted by Ahern and Dittmar (2012) and Adams and Ferreira (2009), which show a negative or neutral relationship between female board representation and corporate outcomes.

However, other scholars such as Gul, Srinidhi, and Ng (2011), Conyon and He (2017), Chen, Leung, and Evans (2018), and Mukarram, Ajmal, and Saeed (2018) highlight the importance of legal and institutional frameworks in the relationships between board gender diversity and corporate outcomes, and find a positive relationship in

Table 5. Analyst coverage, female VC board directors and innovation.

	R&D ratio		Patent	
Variables	(1)	(2)	(3)	(4)
Analyst_coverage	0.029**	−0.100***	0.008	−0.044***
	(2.311)	(−3.044)	(1.404)	(−2.661)
Female VC board director∗analyst_coverage		0.129***		0.052***
		(4.198)		(3.247)
Leverage	−1.044*	−1.010	0.010	0.023
	(−1.654)	(−1.593)	(0.036)	(0.087)
Total assets	1.800***	1.804***	0.141	0.142
	(5.649)	(5.656)	(1.208)	(1.220)
Sales	−2.339***	−2.347***	0.373***	0.369***
	(−8.957)	(−8.968)	(3.837)	(3.792)
Intangible assets	−7.870**	−7.822**	1.305	1.325
	(−2.240)	(−2.226)	(1.062)	(1.076)
Out_ratio	−3.322**	−3.333**	0.237	0.232
	(−2.180)	(−2.186)	(0.399)	(0.392)
Board size	0.065	0.069	−0.000	0.001
	(0.202)	(0.215)	(−0.002)	(0.012)
ROA	9.476***	9.564***	−1.018	−0.982
	(3.414)	(3.435)	(−1.028)	(−0.988)
Constant	13.820***	13.871***	−8.264***	−8.244***
	(4.496)	(4.510)	(−5.895)	(−5.876)
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
No. of obs.	1114	1114	1114	1114
R^2	0.416	0.416	0.497	0.497

Notes: OLS estimation results. *R&D ratio*, R&D expenditure divided by total sales∗100; *Patent*, the log value of the total number of patent application. Independent variables: *Analyst_coverage*, the number of analysts (teams) that have tracked and analyzed the company in a year; *Female VC board director∗analyst_coverage*, an interaction term between *female VC board director* and *analyst_coverage*. *Leverage*, the sum of short-term and long-term debts divided by total assets; *Total assets*, the log value of firm's total assets; *Sales*, the log value of total sales; *Intangible assets*, total assets minus property, plant and equipment divided by total assets; *Out_ratio*, the fraction of independent board directors; *Board size*, the log value of the number of board directors; *ROA*, the earnings before interest, taxes, depreciation, and amortization divided by total assets. All regressions include yearly and industry fixed effects. The robust t-statistics are reported in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

their studies. In particular, our research is consistent with the results shown in Adams and Ferreira (2009) that although the average impact of female board representation on firm performance is negative, the effect turns to be positive in the weak corporate governance environment.

In addition to the main variables of interest, we also included control variables in the regression analysis. The correlations between these control variables and innovation measures align with previous findings in the literature. For instance, *total assets* and *ROA* are positively correlated with innovation measures, indicating that big and profitable firms have more incentive to engage in innovative projects. Overall, our findings suggest that the negative relationship between external stock market pressure, as indicated by analyst coverage, and innovation is weaker for firms with women VC directors on the board.

4.4. Female VC directors, product market competition and innovation

In this section, we test our third hypothesis regarding firms' market competition level and female VC directors' influence on innovation. We follow Chen, Leung, and Evans (2018) to construct measure of industry concentration. We measure industry concentration ratio as sales ratio of the four largest firms in a 3-digit code industry over total sales of all firms in that industry in a given year. The high ratio of sales concentration indicates low level of competition of that industry.

To examine the influence of female VC directors on innovation in different market competition contexts, we divide our sample into two subsamples: firms operating in high-competition industries and firms operating in low-competition industries, based on the four-firm concentration ratio. Firms with a concentration ratio above the sample median for a given year are considered to have a low product competition level. We then regress

Table 6. Product market competition, female VC board directors and innovation.

	Low competition		High competition	
	R&D ratio	Patent	R&D ratio	Patent
Variables	(1)	(3)	(4)	(5)
Female VC board director	0.005*	0.630***	−0.004	0.312***
	(1.693)	(5.184)	(−1.262)	(2.954)
Leverage	−0.010	−2.096***	−0.011	−0.106
	(−1.246)	(−5.542)	(−0.980)	(−0.298)
Total assets	0.010***	0.354**	0.012*	0.871***
	(2.692)	(2.094)	(1.770)	(5.739)
Sales	−0.014***	0.043	−0.018***	−0.375***
	(−5.043)	(0.316)	(−3.497)	(−2.755)
Intangible assets	−0.018	−2.831	−0.070	−1.024
	(−0.675)	(−1.583)	(−1.191)	(−0.764)
Out_ratio	−0.004	1.566**	−0.010	1.675***
	(−0.318)	(2.175)	(−0.417)	(2.961)
Board size	0.001	0.076	0.003	−0.020
	(0.416)	(0.581)	(0.813)	(−0.208)
ROA	0.080***	−4.021***	0.041	−1.937*
	(2.605)	(−3.488)	(1.271)	(−1.892)
Constant	0.095***	−6.913***	0.193**	−9.487***
	(3.137)	(−4.143)	(2.242)	(−6.409)
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
No. of obs.	754	754	662	662
R^2	0.444	0.513	0.411	0.537

Notes: OLS estimation results. Dependent variables: *R&D ratio,* R&D expenditure divided by total sales; *Patent,* the log value of the total number of patent application. Independent variable: *Female VC board director*, a dummy variable equals to one if a firm has at least one female VC director on its board and zero if otherwise. *Leverage*, the sum of short-term and long-term debts divided by total assets; *Total assets*, the log value of firm's total assets; *Sales*, the log value of total sales; *Intangible assets*, total assets minus property, plant and equipment divided by total assets; *Out_ratio*, the fraction of independent board directors; *Board size*, the log value of the number of board directors; *ROA*, the earnings before interest, taxes, depreciation, and amortization divided by total assets. All regressions include yearly and industry fixed effects. The robust t-statistics are reported in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

innovation measures on female VC board directors separately for firms in low-competition industries and high-competition industries. The estimation results are reported in Table 6. Column (1) and (2) in Table 6 shows that the coefficient estimates of *female VC board director* are significant and positive (0.005, $p < 0.1$, and 0.630, $p < 0.01$).

In contrast, coefficients on *female VC board director* reported in Column (4) and (5) of Table 6 are either insignificant or lower than those in the previous two columns, indicating that the influence of female VC board directors is more prominent in less competitive industries. Based on the previous discussion, the quiet life hypothesis suggests that managers tend to avoid engaging in innovative and inventive activities. However, female directors often exhibit a management style characterized by a focus on long-term value creation, promoting collaboration and inclusivity, and prioritizing long-term performance improvements. This unique management approach of female directors reduces managerial slack and curbs myopic investment behaviors. It also leads to a redirection of resources towards innovative and value-enhancing projects through improved board monitoring activities (Bertrand and Mullainathan 2003).

In highly competitive industries, firms face greater risks for survival, and managers experience increased pressure to meet profit targets (Chen, Leung, and Evans 2018). Consequently, the challenges associated with managerial shirking and the need for heightened supervision from female VC board directors are less prevalent in firms operating within highly competitive environments. Overall, the estimation results support our **H4** positing that the positive correlation between female VC board representation and firm innovation is stronger in firms with low market product competition.

5. Robustness checks

Prior literature provides several measures of women's board representation, including the dummy, number and fraction of female directors on the board (Adams and Ferreira 2009; Ahern and Dittmar 2012; Bennouri et al. 2018; Chen et al. 2019). In the robustness checks, we use the fraction of female VC directors on the board, *female VC ratio,* as an alternative proxy for female VC board representation. As an addition to all patents applied, we also include the number of invention applications that the company files in a year to better capture the output of technological innovation[3] (Wang, Li, and Furman 2017). We also denote *patent grants* and *invention grants* as the log value of the total number of inventions and patents granted in the same year of the application, respectively, following Wang, Li, and Furman (2017).

To further address identification issue of whether the superior performance of the firms with female VC directors on the board is driven by female VCs or certain unobserved variables, we use an IV of cultivated land per capita of the province where the project company is located. According to Duflo (2012), women empowerment and economic development are closely related. Females in developing areas are treated differently than their brothers, lagging behind males in many domains. However, the bidirectional relationship between regional economic development and women's empowerment, i.e. improving the ability of female's access to constituents of development – in particular health, education, rights, business and political participation. In one way, development alone can play a major role in alleviating inequality between men and women; in the other way, woman empowerment can accelerate development.

To drive down the reverse causality issue, we use cultivated land per capita to represent economic development, as it is closely related to economic development but does not seem to be influenced by women's empowerment. Lichtenberg and Ding (2009) highlight that industrial land expansion serves as a pivotal driver for economic growth in China. The substantial surge in rapid urbanization and industrial expansion has led to the imperative reduction of land allocated for agricultural purposes. Consequently, regions characterized by lower per capita cultivated land exhibit a more advanced level of economic development.

In the context of VC directors, Female VCs are more likely to join firms in regions with more open culture and higher level of economic development. In other words, firms located in places with limited land availability per capita (*landpp*) are more attractive to female VCs, and the influence of women VC directors on corporate outcomes are more pronounced in these firms. Therefore, this IV is a good predictor of a firm being backed by a female VC director in the first-stage estimation, because it is associated with the presence of female VC directors in the project firms but is not directly correlated with the innovation performance of the firms.

Table 7 presents the results of the two-stage least square estimation for the dependent variables, *R&D ratio* and *patent*, where *female VC board director* is instrumented by *landpp*. In the first-stage estimations, we regress *female VC board director* on *landpp* with same control variables in our baseline regressions. In Panel A of Table 7, the regression results for the dependent variables, *R&D ratio* and *Patent*, are presented in columns (1) and (2), respectively. The significant and negative coefficients on *landpp* in Column (1) and (2) confirm that *landpp* is a statistically qualified IV for *female VC board director*. Moreover, the *p*-value of Kleibergen-Paap rk LM statistic is 0.000, rejecting the null hypothesis that the IV is under-identified.

Panel B of Table 7 shows the second-stage estimation results of the IV procedure. *Female VC board director* is significantly and positively correlated with innovation input measured by R&D ratio and output measured by the log value of patent number in Column (1) and (2) in Panel B. Stock, Wright, and Yogo (2002) conduct a comprehensive review of the literature on weak instruments and establish benchmarks for the minimum required magnitude of the F-statistic. According to their findings, if there is only one instrument, the critical value of the F-statistic is 8.92. In our analysis, the Cragg-Donald Wald F-statistic is 9.92, which surpasses the critical value specified by Stock, Wright, and Yogo (2002). Therefore, the *landpp* is a qualified IV in our estimations.

The results of the second-stage estimation are displayed in Panel B of Table 7. In Column (1) and (2) in Panel B of Table, the coefficient estimates on *female VC board director* in all regressions are both positive and statistically significant at 1% level. For *R&D ratio* and *Patent*, the coefficient estimates on *female VC board director* are 0.213 and 4.049, respectively. These results further highlight the significant positive influence of female VC directors on project firms' innovation. Overall, these results are consistent with those shown in Table 3, confirming our hypothesis of the positive impacts of female VC board representation and firm innovation.

Table 7. Two-stage estimations for female VC board directors' effects.

Panel A First-stage Estimation of the Two-stage Regression		
	Female VC board director	Female VC board director
	(1)	(2)
Landpp	−0.030***	−0.030***
	(−3.47)	(−3.47)
Constant	0.484***	0.484***
	(3.96)	(3.96)
R-square	0.043	0.043
Panel B Second-stage Estimation of the Two-stage Regression		
	R&D ratio	Patent
	(1)	(2)
Female VC board director	0.213***	4.049***
	(3.466)	(2.754)
Leverage	−0.012*	−1.181***
	(−1.767)	(−7.262)
Total assets	0.004	0.361***
	(0.736)	(2.940)
Sales	−0.004	0.228*
	(−0.717)	(1.723)
Intangible assets	0.044	1.339*
	(1.406)	(1.863)
Out_ratio	0.106***	3.410***
	(3.019)	(4.071)
Board size	−0.021***	−0.068
	(−3.155)	(−0.424)
ROA	0.119***	0.819
	(4.873)	(1.392)
Constant	−0.022	−12.293***
	(−0.567)	(−13.083)
Year	Yes	Yes
Industry	Yes	Yes
No. of obs.	7733	7733
R-square	−7.828	−0.770
Cragg-Donald Wald F statistic:	9.919	9.919

Notes: 2SLS estimation results for *R&D ratio* and *Patent*, where *female VC board director* is instrumented by *landpp*. Dependent variables: *R&D ratio*, R&D expenditure divided by total sales; *Patent*, the log value of the total number of patent application. Independent variable: *female VC board director*, a dummy variable equals to one if a firm has at least one female VC director on its board and zero if otherwise. Instrumental variable: *Landpp*, cultivated land per capita of the province where the project company is located. *Leverage*, the sum of short-term and long-term debts divided by total assets; *Total assets*, the log value of firm's total assets; *Sales*, the log value of total sales; *Intangible assets*, total assets minus property, plant and equipment divided by total assets; *Out_ratio*, the fraction of independent board directors; *Board size*, the log value of the number of board directors; *ROA*, the earnings before interest, taxes, depreciation, and amortization divided by total assets. All regressions include yearly and industry fixed effects. The robust t-statistics are reported in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

To check robustness, we also use alternative samples, measures and proxies for female VC representation and innovation for our estimations for the female board representation hypothesis. First, we use a subsample of high-tech firms based on the high-tech industry (Manufacturing Industry) classifications (2013) issued by the Chinese SSB as used by Liu and Buck (2007) in their study to evaluate women VC directors' influence on high technology manufacturing firms. The results are shown in Table 8. As shown in Column (1)-(3) of Table 8, the coefficient estimates on *female VC board director* are positive and significant at 1% level for all measures of innovation performance, indicating that the influence of women VC board directors on project firms' innovation is significant in high-tech industries (0.021, $p < 0.01$, 0.425, $p < 0.01$, and 0.245, $p < 0.01$). The re-estimation results confirm our finding that women board VC members have positive impacts on firm R&D ratio and patents.

Table 8. Robustness check 1: female VC board directors and innovation (high-tech PSM sample).

	R&D ratio	Patent	Invention
Variables	(1)	(2)	(3)
Female VC board director	0.021***	0.425***	0.245***
	(3.850)	(3.755)	(3.039)
Leverage	−0.002	−0.613*	−0.173
	(−0.230)	(−1.934)	(−0.709)
Total assets	0.026***	0.852***	0.661***
	(7.826)	(5.948)	(5.779)
Sales	−0.031***	−0.359***	−0.278***
	(−10.413)	(−2.957)	(−3.017)
Intangible assets	−0.103**	0.898	0.408
	(−2.258)	(0.758)	(0.484)
Out_ratio	−0.042**	1.631***	1.566***
	(−2.319)	(3.001)	(3.971)
Board size	0.001	0.038	−0.042
	(0.338)	(0.410)	(−0.634)
ROA	0.152***	−2.897***	−1.077*
	(5.545)	(−3.539)	(−1.653)
Constant	0.095***	−9.686***	−7.605***
	(2.692)	(−6.099)	(−5.865)
Year	Yes	Yes	Yes
Industry	Yes	Yes	Yes
No. of obs.	918	881	881
R^2 / Pseudo R^2	0.290	0.498	0.448

Notes: OLS estimation results using PSM matched sample of firms in high-tech industries. Dependent variables: *R&D ratio*, R&D expenditure divided by total sales; *Patent*, the log value of the total number of patent application. Independent variable: *Female VC board director*, a dummy variable equals to one if a firm has at least one female VC director on its board and zero if otherwise. *Leverage*, the sum of short-term and long-term debts divided by total assets; *Total assets*, the log value of firm's total assets; *Sales*, the log value of total sales; *Intangible assets*, total assets minus property, plant and equipment divided by total assets; *Out_ratio*, the fraction of independent board directors; *Board size*, the log value of the number of board directors; *ROA*, the earnings before interest, taxes, depreciation, and amortization divided by total assets. All regressions include yearly and industry fixed effects. The robust t-statistics are reported in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Overall, the positive association between female board VC directors and firm innovation is robust to the use of alternative sample.

Moreover, in Robustness checks 2 of Table 9, we use alternative measures of innovation and women VC board representation. In particular, we use the numbers of patent and invention grants as well as innovation efficiency to measure innovation performance in Table 9. In Column (1)–(3) of Table 9, the coefficient estimates on women board director are all significant and positive for all measures of innovation (0.525, $p < 0.01$, 0.274, $p < 0.01$, and 0.032, $p < 0.01$). Similarly, the positive coefficient estimates of the female VC ratio reported in Columns (4) and (5) of Table 9 are statistically significant at the 1% level in all regressions (4.421, $p < 0.01$, and 2.828, $p < 0.01$), suggesting that female VC board representation promotes innovation.

Overall, these additional tests offer general support for our predictions of the positive influence of female VC directors' board representation on firm innovation performance. In particular, the negative impact of managerial myopia is less severe when female VC directors serve on boards.

6. Conclusions

Amid the global push towards placing more women in the boardroom, the roles played by female directors have become increasingly debated in academic society, particularly for firms located in developing economies with weak legal infrastructure and governance systems. Moreover, as the second largest VC market, studies on the roles played by VCs after investments in portfolio firms' innovation in China generate interesting discussions.

Table 9. Robustness check 2: female VC board directors and innovation (alternative measures).

	Patent Grant	Invention Grant	Innoefficiency	Patent	Invention
Variables	(1)	(2)	(3)	(4)	v(5)
Female VC board director	0.525***	0.274***	0.032***		
	(6.257)	(5.892)	(6.855)		
Female VC ratio				4.421***	2.828***
				(11.861)	(9.985)
Leverage	−1.413***	−0.706***	−0.052***	−0.801***	−0.367*
	(−5.433)	(−4.808)	(−3.308)	(−3.081)	(−1.806)
Total assets	0.499***	0.272***	0.041***	0.471***	0.372***
	(4.653)	(4.101)	(6.067)	(4.156)	(4.305)
Sales	−0.087	−0.075	−0.018***	−0.108	−0.111
	(−0.969)	(−1.399)	(−3.230)	(−1.168)	(−1.599)
Intangible assets	−1.876*	−0.372	−0.164***	−1.872*	−1.063
	(−1.920)	(−0.735)	(−2.750)	(−1.960)	(−1.603)
Out_ratio	1.399***	0.857***	0.083***	1.051***	0.820***
	(3.244)	(3.800)	(3.285)	(2.678)	(2.723)
Board size	0.013	−0.028	0.002	0.014	−0.015
	(0.169)	(−0.733)	(0.370)	(0.207)	(−0.302)
ROA	−3.174***	−1.093***	−0.137***	−2.514***	−1.272**
	(−5.000)	(−3.003)	(−3.342)	(−3.625)	(−2.358)
Constant	−7.119***	−3.494***	−0.420***	−6.107***	−4.530***
	(−6.487)	(−5.467)	(−6.322)	(−5.070)	(−4.887)
Year	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes
No. of obs.	1416	1416	1314	1416	1416
R^2	0.522	0.402	0.499	0.548	0.475

Notes: OLS estimation results using PSM matched sample. Dependent variables: *Patent grant*, the log value of the total number of patent grants; *Invention grant*, the log value of the total number of invention patent grants; *Innoefficiency*, the log value of patent applications divided by the log value of R&D ratio; *Patent*, the log value of the total number of patent application; *Invention*, the log value of the total number of invention applications. Independent variable: *Female VC board director*, a dummy variable equals to one if a firm has at least one female VC director on its board and zero if otherwise; *Female VC ratio*, the number of female VC board directors divided by total number of directors on the board. *Leverage*, the sum of short-term and long-term debts divided by total assets; *Total assets*, the log value of firm's total assets; *Sales*, the log value of total sales; *Intangible assets*, total assets minus property, plant and equipment divided by total assets; *Out_ratio*, the fraction of independent board directors; *Board size*, the log value of the number of board directors; *ROA*, the earnings before interest, taxes, depreciation, and amortization divided by total assets. All regressions include yearly and industry fixed effects. The robust t-statistics are reported in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

In this study, we estimate the impacts of the participation of female VC directors in the boardroom on innovative corporate activities of Chinese listed manufacturing companies. Specifically, we examine the underlying mechanisms through which female VCs exert influence.

We find that both the innovation input and output of firms with female VC board directors are higher than those of firms without female VC board directors after utilizing the PSM algorithm to control for selection bias. In particular, the presence of women VC directors on corporate boards significantly weakens the adverse effect of managerial myopia on long-term innovation. Generally, these findings provide empirical evidence on female VCs' contributions to portfolio firms apart from financial support. As better monitors and advisors, female VCs in China add value to their investees through improved board effectiveness, which reduces managerial short-termism and improves board transparency, and they contribute to the sustainable development of companies in the long run.

Overall, our findings correspond to the existing literature on board composition and firm performance in other developing countries in which decent internal governance structures, such as an independent board, contribute to a reduction in agency costs (Black and Kim 2012; Dahya et al. 2007). Future research in the field can explore alternative mechanisms by which female VC investors stimulate innovation, including examining their impact on risk management, while also evaluating the effects of individual VC investors' demographic characteristics and social networks on the financial and social performance of portfolio firms.

Notes

1. Chinese high-tech industries include: Medical and Pharmaceutical Products, Aircraft and Spacecraft, Electronic and Telecommunications Equipment, Computer and Office Equipment and Medical Equipment and Meters.
2. The PSM matching results are reported in Appendix 2. The differences in the average treatment effects (ATT) on *R&D ratio* and *patent* between the control and treatment for the two pairs of groups equal to 0.009 with *t*-value of 8.68 and 0.585 with *t*-value of 22.51 after matching, respectively.
3. There are three broad categories of patents in China's patent system, including new design, new utility and invention, arranged in order of increasing value in terms of commercial and innovation (Wang, Li, and Furman 2017).

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Appendices

Appendix 1. Definition of key variables and data source

Variables	Description	Source
Dependent Variables		
R&D ratio	R&D expenditure divided by total sales.	CSMAR
Patent	The total number of all patent applications in natural logarithm format.	CSMAR
Independent Variables		
Female VC board director	A dummy variable equals to 1 if a firm has at least one female VC director on the board and 0 if otherwise.	IPO prospectus
Short_invest ratio	The short investment divided by total assets.	Wind
Analyst_coverage	The number of analysts (teams) that have tracked and analyzed the company in a year.	CSMAR
Control Variables		
Leverage	The sum of short-term and long-term debts divided by total assets.	Wind
Total assets	The log value of firm's total assets.	Wind
Sales	The log value of total sales.	Wind
Intangible assets	Total assets minus property, plant and equipment divided by total assets.	Wind
Out_ratio	The fraction of independent board directors.	CSMAR
Board size	The log value of the number of board directors.	CSMAR
ROA	The earnings before interest, taxes, depreciation, and amortization divided by total assets.	Wind

Appendix 2. PSM matching results (a)

Panel A: Average treatment effect				
	Treated firms	Control firms		
Variables	ATT	ATT	Difference	t-stat
R&D ratio	0.052	0.043	0.009***	8.68
Panel B: Before matching				
	Treated firms	Control firms		
Variables	Mean	Mean	Difference	t-stat
Leverage	0.299	0.285	0.014***	2.72
Total assets	21.196	21.209	−0.013	−0.52
Public age	0.741	0.763	−0.022	−1.39
Intangible assets	0.041	0.042	−0.001	−0.71
Board size	2.219	2.210	0.009*	1.82
ROA	0.583	0.066	0.517***	−6.19
Panel C: After matching				
	Treated firms	Control firms		
Variables	Mean	Mean	Difference	t-stat
Leverage	0.299	0.292	0.007	1.08
Total assets	21.195	21.187	0.008	0.25
Public age	0.741	0.744	−0.003	−0.16
Intangible assets	0.041	0.041	−0.000	−0.39
Board size	2.219	2.216	0.003	0.63
ROA	0.058	0.060	−0.002	−0.94

Notes: This table reports the average treatment effects and the balance tests for relevant variables based on a sample in which firms with female VC board directors are matched with firms without female VC board directors using the propensity score matching algorithm. Panel A refers to the estimates of the average treatment effects. Panel B and C report the t-test results for the equality of the means before and after the matching for the relevant variables that were used as a covariate in the matching procedures. *Leverage*, the sum of short-term and long-term debts divided by total assets; *Total assets*, the log value of firm's total assets; *Public age*, the log value of the number of years since IPO; *Intangible assets*, total assets minus property, plant and equipment divided by total assets; *Board size*, the log value of the number of board directors; *ROA*, the earnings before interest, taxes, depreciation, and amortization divided by total assets. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Appendix 2. PSM matching results (b)

Panel A: Average treatment effect				
	Treated firms	Control firms		
Variables	ATT	ATT	Difference	t-stat
Patent	1.035	0.045	0.585***	22.51
Panel B: Before matching				
	Treated firms	Control firms		
Variables	ATT	ATT	Difference	t-stat
Leverage	0.333	0.454	−0.121***	−14.32
Total assets	20.89	20.021	0.869***	19.17
Firm age	0.608	2.293	0.741***	16.45
Intangible assets	0.044	0.054	−0.010***	−5.73
Board size	2.141	0.230	1.911***	80.48
ROA	0.798	0.129	0.669***	−16.66
Panel C: After matching				
	Treated firms	Control firms		
Variables	ATT	ATT	Difference	t-stat
Leverage	0.396	0.377	0.019***	3.12
Total assets	20.689	20.327	0.362***	10.93
Firm age	2.522	2.516	0.006	0.37
Intangible assets	0.051	0.056	−0.005***	−4.26
Board size	2.057	2.078	−0.021	−1.10
ROA	0.092	0.118	−0.026***	−11.90

Notes: This table reports the average treatment effects and the balance tests for relevant variables based on a sample in which firms with female VC board directors are matched with firms without female VC board directors using the propensity score matching algorithm. Panel A refers to the estimates of the average treatment effects. Panel B and C report the t-test results for the equality of the means before and after the matching for the relevant variables that were used as a covariate in the matching procedures. *Leverage*, the sum of short-term and long-term debts divided by total assets; *Total assets*, the log value of firm's total assets; *Public age*, the log value of the number of years since IPO; *Intangible assets*, total assets minus property, plant and equipment divided by total assets; *Board size*, the log value of the number of board directors; *ROA*, the earnings before interest, taxes, depreciation, and amortization divided by total assets. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$.

Appendix 3. Correlation matrix

	V1	V2	V3	V4	V5	V6	V7
Female VC board director							
R&D ratio	0.0696*						
Patent	0.3349*	0.0554*					
Leverage	−0.2699*	−0.2183*	−0.1939*				
Total assets	0.3511*	−0.1380*	0.4354*	0.1165*			
Sales	0.1864*	−0.3032*	0.2636*	0.2864*	0.8695*		
Intangible assets	−0.1114*	−0.0307	−0.0993*	0.0601*	−0.0894*	−0.0730*	
Out_ratio	0.8158*	0.0622*	0.3644*	−0.2770*	0.3603*	0.1798*	−0.0845*
Board size	0.8442*	0.0465*	0.3556*	−0.2598*	0.3645*	0.1987*	−0.0903*
ROA	−0.3099*	0.0627*	−0.3511*	−0.1368*	−0.4807*	−0.2534*	0.0689*
	V8	V9	V10				
Out_ratio							
Board size	0.8957*						
ROA	−0.3247*	−0.3107*					

Note: $^{*}p < 0.05$.