International Review of Economics and Finance 93 (2024) 772–788

Contents lists available at ScienceDirect

International Review of Economics and Finance

journal homepage: www.elsevier.com/locate/iref

Does governmental venture capital (GVC) advance green innovation? Big data evidence from China

Yuchen Li [a], Jiayin Meng [b], Ruifan Zhou [c], Ying Wang [d,*]

[a] *Agricultural Bank of China, 69 Jianguomen Nei Street, Beijing, 100005, China*
[b] *The Bartlett School of Sustainable Construction, University College London, London, WC1E 6BT, United Kingdom*
[c] *China Sichuan Administration Institute, 43 Guanghuacun Street, Chengdu, 610071, China*
[d] *Faculty of Business and Law, Anglia Ruskin University, East Road, Cambridge, CB1 1PT, United Kingdom*

ARTICLE INFO

JEL classification:
G24
M13
O38
L26
Q55

Keywords:
Governmental venture capital (GVC)
Green innovation
Patents
Certification effect
PSM method

ABSTRACT

This paper examines the impact of governmental venture capital on green innovation utilizing a unique and comprehensive dataset in China between 2009 and 2018. Our results consistently reveal significant and positive effects of GVCs on green innovation, a result derived from the analysis of 317,870 firm-year observations conducted through a difference-in-differences and propensity score matching panel approach. Moreover, GVCs investments indicate a significant but smaller effect when they invest in start-ups. Following GVC investments, companies tend to attract additional private and other governmental financing. Interestingly, GVCs structured as limited partnerships appear to stimulate more green innovation compared to corporate-venture-structured GVCs.

1. Introduction

Considered as a crucial strategy for achieving environmental protection, green innovation is categorized into four domains: product, process, managerial, and technological. These encompass various areas such as renewable energy, new materials, pollution reduction, and recycling technologies (Castellacci and Lie, 2017; Cuerva et al., 2014; Tseng et al., 2013). Previous evidence suggests that there is a positive relationship between green innovation and sustainable economic growth. Specifically, successful green innovations not only augment resource efficiency and mitigate environmental risks (Castellacci and Lie, 2017), but also improve employment status (Kunapatarawong and Martínez-Ros, 2016 and upgrade service quality (Roy & Khastagir, 2016). The 'double externality' entailed by green innovation as illustrated by Rennings (1998) shows that apart from the conventional positive technological spillovers often linked to basic R&D activities, it generates additional positive externalities. These externalities work to reduce external costs in both innovation and diffusion phases (Cuerva et al., 2014) and improve firms' financial performance (Xie et al., 2019a). Green innovation, defined as products or processes that contribute to a reduction of environmental burdens or to ecologically specified sustainability targets (Rennings, 2000), can enable companies to achieve great efficiencies, increase their competitive advantages on market position, customer attraction and reputation enhancement through effective corporate management, as well as enhance their positive green image (Chang, 2011; Gema et al., 2016; Tu and Wu, 2021).

* Corresponding author.
E-mail address: ying.wang@aru.ac.uk (Y. Wang).

https://doi.org/10.1016/j.iref.2024.03.056
Received 6 September 2023; Accepted 20 March 2024
Available online 21 March 2024

However, investments in green innovation by the banking sector and private capital remain constrained due to its substantial initial costs (Eyraud et al., 2011), the significant and enormous risks and uncertainties (Bernauer et al., 2007), the lack of consistent data for evaluating the impact of green innovation on firms, and the considerably low rate of return from green innovation in the short term. Serving as a complement to private venture capital (PVC), governmental venture capital (GVC) pursues investments that will benefit society or localize public benefits particularly for underprivileged regions, correct supply-side failures in domestic VC markets, fill the equity gap and potentially crowd in the development of VC markets (see detailed discussion of GVCs by Colombo et al., 2016). Evidence suggests that GVCs have increasingly attracted attention from governments and public authorities (Munari and Toschi, 2015). Over the past two decades, governments around the world have responded to this financing challenge by establishing governmental venture capital initiatives aimed at bridging the financing gap for green innovation. Since then, GVCs have provided a dedicated national and regional investment platform to address the growing needs of the high-tech industry, localize job creation, seed private sector investment, enhance regional development, and work towards long-term sustainable goals.

Previous studies show that GVCs foster the development of high-growth companies and alleviate the capital gap of young innovative firms (Faria and Barbosa, 2014; Soleimani Dahaj and Cozzarin, 2019), facilitate the access of PVC funds (Alperovych et al., 2020; Guerini and Quas, 2016; Lerner, 2002); tend to postpone the exit from those ventures that exert positive impact on social payoffs even with less satisfactory financial returns (Buzzacchi et al., 2013); less likely to be acquired or exit via IPOs (Cumming and Johan, 2008); and provide quicker exit and perform better in terms of exit outcomes (Cumming and Johan, 2010; Cumming et al., 2014). On the contrary, a large body of literature show that GVCs are often ineffective (Mason, 2016): have limited or negligible effect on company's performance measured by innovation, growth, and efficiency (Grilli and Murtinu, 2014; Bertoni and Tykvová, 2015; Colombo et al., 2016; Alperovych et al., 2015; Alperovych et al., 2020); display significant reductions in productivity (Alperovych et al., 2015); fail to crowd in private VCs to the companies (Armour and Cumming, 2006; Bertoni et al., 2015); less likely to raise series equity compared to independent VCs backed firms (Vanacker et al., 2014); and tends to underperform due to the lower engagement of GVCs in coaching and value adding activities in those ventures (Colombo et al., 2016).

Despite the growing attention on the socio-economic and environmental values of GVCs, little is known about the impact of GVCs on green innovation (Dong et al., 2021). Aligned with the global sustainable growth agenda, a significant objective of GVCs is to encourage innovation that drives economic growth, with a special focus on green innovation and environmental improvement initiatives rooted in public policy considerations. However, to the best of our knowledge, mechanisms by which GVCs can drive companies to transition towards significant green innovation remain uncertain and no studies provide empirical evidence of GVCs' impact on green innovation through comprehensive big dataset analyses. Our paper aims to reduce these gaps by investigating three key research questions: (1) Can GVCs promote green innovations of the ventures? (2) Will GVCs promote firms' green innovation through its "certification effect"? and (3) Can GVCs in corporate venture structure encourage more green innovation than those structured in limited partners?

To evaluate the impact of GVCs on green innovation, we create a comprehensive and big dataset comprising a distinctive longitudinal sample of 11,645 firms that successfully received GVC funds from 2009 to 2018 in China. Adopting the difference-in-differences (DID) and propensity score matching (PSM) panel settings, our results using 317,870 firm-year observations show that the impact of GVC funds on green innovation in China is positive and significant. Specifically, firms receiving GVC funds increase their number of granted green patents by 3.8%–9.8%, all significant at the 1% level. After controlling for the potential endogeneity and self-selection bias problems by adopting the PSM method, our results remain unchanged. We further find that there is a significant but smaller effect of GVC investments on green innovation when the ventures are start-ups. Furthermore, results show that GVCs help alleviate financial constraints of the ventures and significantly promote green innovation by attracting more PVC and GVC funds following the initial investments by GVCs. Interestingly, contrary to our hypothesis, our findings show that GVCs structured in limited partnerships, compared with GVCs in corporate venture structure in China, are more effective in promoting firms' green innovation in China.

Given the potential constraints of utilizing green patent data to measure green innovation, we further explore enhancements in the quality of green innovation as a means to assess improvements in green innovation. Our findings show significant and positive effect, which captures the economic 'values' of GVCs' investments on green innovation from other perspectives. Finally, we perform a series of additional tests to verify our results and find consistent results for all non-public traded companies, even when accounting for natural disasters in China. Our results are robust after controlling firm and institutional variables, and consistent with several possible alternative robustness checks based on the characteristics of GVC investments.

In the following sections, we review the relevant literature and propose three main hypotheses in Section 2. Section 3 presents the data and methods adopted in this research. Results and robustness tests are discussed in section 4 and section 5, respectively. Section 6 concludes.

2. Literature and hypothesis development

Governmental venture capital funds play a pivotal role in contributing a pool of capital available to companies. They have allocated funds to areas where market failures are evident (Cumming, 2007; Lerner, 2002), such as environmental protection through green innovation like new materials and pollution reduction technologies (Castellacci and Lie, 2017; Cuerva et al., 2014). To drive companies to engage in environmental protection, previous research indicates that there are two important factors: government environmental intervention and environmental consciousness of consumers (Chen, 2008; Liu et al., 2021). The Porter Hypothesis proposed by Porter and van der Linde (1995) suggested that environmental regulation positively influenced firms' performance by fostering green innovation and competitiveness (Liu et al., 2021; Xie et al., 2017). This hypothesis motivates further investigation into the impact of government regulations on green innovation (Brunnermeier and Cohen, 2003; Horbach et al., 2012). On the contrary, the 'inhibitory effect' argued that environmental regulations might result in a reduction or partial reduction in the productivity of green product innovation (Gray and Shadbegian, 2003; Lanoie et al., 2008; Shen et al., 2020).

To date, previous studies examined the impact of different government environmental intervention on green innovation in various perspectives, including compulsory environmental protection laws (Lanoie et al., 2008; Liu et al., 2021), environmental information disclosure (Ding et al., 2022), pollution abatement expenditure (Brunnermeier and Cohen, 2003), government R&D subsidies (Bai et al., 2019; Xie et al., 2019b) and emission taxes (Yi et al., 2021). Although governments have implemented an array of public policies to foster the development of environment-friendly business (Bürer and Wüstenhagen, 2009; Criscuolo and Menon, 2015), green innovation process still confronts severe capital constraints because it requires long-term strategic investment and abundant financial support (Wei et al., 2015). Information asymmetries between ventures and capital markets (Hall and Lerner, 2010), stemming from the lack of ventures' track record (Ghosh and Nanda, 2010), high ratio of intangible assets (Denis, 2004) and difficulties in evaluation of complex technologies (Amore and Bennedsen, 2016), exacerbate these barriers. Moreover, green innovation often requires a longer project duration to become profitable compared to non-green innovation (or conventional innovation). This extended investment period can potentially affect the returns of VCs in green investments.

In response to this challenge, GVCs, functioning as government-affiliated entities by directly investing in newly emerging ventures (Soleimani Dahaj and Cozzarin, 2019), were established to rectify this market failure, primarily by addressing the insufficient supply side of the market (Lerner, 2002). Over the years, GVCs have consistently been recognized for their role in providing financial resources to relax investment constraints for commercial start-ups (Bertoni et al., 2015; Cumming, 2007) and to support invention and innovation within firms (Bertoni and Tykvová, 2015; Xiang et al., 2022). Unlike PVCs, which source capital from private institutional investors and typically present strong financial objectives, GVCs are generally expected to take into account economic policy objectives and social goals established by public entities. Apart from financial benefits, GVCs tend to support innovation based on public policy considerations, playing vital roles in filling the financial gaps of PVCs (Dong et al., 2021; Li et al., 2021). Intended to seed green companies, GVCs drive green innovation by allocating investments towards exploratory endeavours that promote innovations and inventions. These activities tend to be lengthy, risky and characterized by uncertainty, which can be challenging for PVCs (Bertoni and Tykvová, 2015). As GVCs are not guided exclusively by the financial goals, it tends to focus on longer time-horizon investments for public benefits and positive externalities to alleviate social problems and serve long-term interests (Bertoni and Tykvová, 2015; Colombo et al., 2016). Considering the dual externalities associated with green innovation, GVCs often serve as a complement to address the under-investment issues in this domain. Investments made by GVCs in the public interest, in alignment with governmental goals and political agendas around the world, are more inclined to promote the advancement of green innovation. This, in turn, contributes to both environmental protection and the welfare of society. Given the existing literature highlights the predominant involvement of GVCs in green innovation, we propose the first hypothesis below.

H1. Investments from GVCs promote green innovations within companies.

Many governments across the world have established GVCs to complement the limited supply of PVCs, with a potential added value to facilitate access to PVCs for their portfolio companies (Guerini and Quas, 2016). Lerner (2002) proposed the 'certification hypothesis', arguing that the selective provision of GVCs can certify the potential of the ventures to PVC investors and this receipt of GVC financing acts as a 'stamp of approval'. This endorsement certifies the venture's potential to other investors and resources, thus increasing the probability for the venture to raise capital due to the reduced uncertainty and lower risk guaranteed by the GVCs. Although some findings indicate a crowding-out effect of GVCs on the total amount of VCs (Armour and Cumming, 2006; Cumming and MacIntosh, 2006), other papers verify some positive impacts of GVCs (Bakhtiari, 2021; Leleux and Surlemont, 2003; Del-Palacio et al., 2012). It is recognized that GVCs surpass PVCs by overcoming severe information asymmetries and avoiding 'herding' with private venture capitalists, especially institutional investors, into more profitable industries (Devenow & Welch, 1996; Cumming, 2008). Specifically, under the guidance of government officials, GVCs are assumed to be able to identify and support ventures that are neglected by private investors, by which the information asymmetries can be diminished and the most promising firms can be identified (Lerner, 2002).

Guerini and Quas (2016) extend this 'certification hypothesis' from another two aspects: one is that compared with PVC, new ventures are willing to share sensitive information for evaluation with GVC investors due to appropriability concerns (Ueda, 2004); the other aspect is that GVC investors can be more motivated to screen investment projects than PVC investors because of free-riding problems. These characteristics again ensure the advantages of GVCs in screening proposals and selecting targets, reducing the information asymmetries, obtaining trusts, and attracting further resources.

It is notable that GVCs, driven by government decision-making and government behaviour, are significant in guiding the market to develop green innovation. Zhang et al. (2022) showed that the higher the political connection level is, the more significant relationship between political connection and green innovation. To connect governments with the companies, GVC financing implies a certified approval of green innovation, which increases the information transparency and helps to attract further investment and corresponding resources for the ventures. In particular, private financing sources, i.e. PVCs can be attracted by such government-backed certificates (Guerini and Quas, 2016). In addition, it can be easier for such certificated green-innovative ventures to obtain financial support from financial institutions according to the theory of 'it pays to be green' (Goss and Roberts, 2011; King and Lenox, 2001; Scholtens, 2006; Zhang et al., 2020). For example, Xing et al. (2021) empirically verify that green innovation promotes access to corporate loans in China. What is more, with the reduction of information asymmetries and the enhancement of trust after receiving GVCs (Lerner, 2000), GVC-funded ventures with green innovative capability can gain competitive advantages in the marketplace (Chang, 2011; McGrath et al., 1996). With subsequent financing sources and competitive advantages obtained via the 'certificate effect' of GVCs, green innovative activities will be further promoted. Meanwhile, by responding to the carbon peaking and carbon neutrality goals, government institutions, companies, and agencies, as well as state-owned enterprises at all levels are inclined to hand over their projects to certified green-innovative ventures for implementation. In a broader context, companies that receive governmental financing tend to possess greater liquidity, making them more appealing to private investors and instilling confidence when approaching external funding (Bakhtiari, 2021). As GVCs play critical roles in financing green innovation through the channel of its 'certification effect', our second hypothesis is developed as follows.

H2. GVCs enhance the stimulation of green innovation through their 'certification effect'.

GVCs can take different organizational and legal forms, among which the most common structures around the world are corporate venture capitalists and limited partners (Cumming, 2005; Cumming et al., 2007, pp. 155–176). Limited partnership form, in other words as independent venture capitalists, refers to the venture capitalists acting as general partners and the outside investors as limited partners. Without taking an active role in fund management and each partner is taxed directly, it is a structure that used to dominate the venture-capital industry in the past. In contrast, corporate venture capitalists are typically stand-alone subsidiaries of nonfinancial corporations; they invest in start-ups on behalf of their corporate partners using corporate funds (Chemmanur et al., 2014) and contributions are encouraged by tax credits and deductions (Cumming and MacIntosh, 2006). From the perspective of investment horizon, unlike corporate venture capitalists which often have indefinite lives, limited partnerships have predetermined and finite lifetimes, which are usually ten years but extensions are often allowed (Gompers and Lerner, 2001).

The ongoing debate revolves around the comparative effectiveness of these two venture capital structures in fostering innovation. Some studies argue the advantages of limited partnerships in venture capital. For example, in comparison with corporate ventures, limited partnerships can be more efficient in resource allocation (Chemmanur et al., 2014). They can professionalize their management teams and foster collaborations within their portfolio firms (Hellmann and Puri, 2002; Lindsey, 2008). In addition, limited partnerships tend to be more specialized in industry expertise (Gompers et al., 2009), which may help to understand the R&D process in a specific industry. Furthermore, a limited partnership, usually favored by private funds, allows significant flexibility and reduces bureaucratic procedures; it is tax efficient and lightly regulated compared to the corporate venture capitalist, which could mitigate agency problems and maximise the returns and performance of the ventures.

Conversely, within the literature supporting corporate venture capitalists, the unique organizational model characterized by longer investment horizons, a broader scope beyond financial returns, and the absence of exclusively performance-driven compensation structures is deemed advantageous. It has been shown that corporate venture capitalists help corporate ventures to nurture innovation and generate greater values compared to limited partnerships (Chemmanur et al., 2014). Lerner (2012) indicates that corporate venture capital is the optimal funding source for innovation. Making investment directly into companies to achieve both financial and strategic objectives (Wadhwa et al., 2016), corporate venture capitalists is a better way to motivate innovation (Lerner, 2012; Chemmanur et al., 2014). It could eliminate agency problems through an effective corporate governance structure, providing a better monitoring system to ensure the quality of the investments, hence facilitating more green innovation. In addition, the parent company of corporate venture capitals could provide knowledge and industry background to foster innovation. Meanwhile, the compensation of the fund managers in corporate venture structure is not closely related to the companies' performance. As a result, their higher risk tolerance might contribute to more innovation support. Although Cumming and MacIntosh (2006) report evidence from Canada that the corporate form of GVCs diminishes contractual flexibility and the free rider problems generate less incentives to monitor fund managers, several studies provide evidence that corporate venture capitalists are superior to limited partnerships in boosting innovation (Chemmanur et al., 2014; Fulghieri and Sevilir, 2009). Therefore, we propose our third hypothesis.

H3. GVCs structured in corporate venture capitalists are likely to foster greater green innovation when compared to those organized as limited partnerships.

3. Data and research design

3.1. Data and sample selection

We manually build a comprehensive dataset, consisting of 11,645 firms that successfully received GVC funds from 2009 to 2018 in China,[1] including start-ups,[2] SMEs, and publicly traded companies.[3] GVCs in China, owned by the governments or operated by the government agents, shall receive no less than 10% of the total value of the funds from local governments and 5% from the central government.[4] To identify GVC funds, we start with screening the official list of full Chinese government funds announced by the National Development and Reform Commission (NDRC). The latest version of this list, released in September 2017, consists of a total of 1078 government master-funds. We combine this official government funds list from NDRC and collect firm data using WIND Global Enterprise Database, a platform that provides comprehensive information for Chinese public and private firms. Following Cumming et al. (2017), we select a government fund as a GVC if there is any key word of 'venture', 'angel', 'incubator', or 'hatcher' in its name. To cover all firms that receive GVC funds in the sample period, we include both government sub-funds and master-funds because sub-funds are common forms in VC portfolios.

To effectively measure the impact of GVCs on firms, we identify matched (or pairing) firms as the control firms for all GVC firms in our dataset. We choose companies that have not receive any VC investments as control firms by considering two primary reasons: 1. Unlike PVC investments which are profit driven decisions, GVC investments in China are driven by the government's policies, normally it is embedded with non-profit purposes and goals. To identify the impact of policy interventions in the DID setting, it is meaningful to match our control firms that are free from any policy intervention and VC investments, i.e., firms that didn't receive any GVC or PVC funds. By doing this, the study can provide insights of the impact of GVCs on green innovation; 2. Due to the big dataset we created for GVCs, there are no existing PVC datasets available to match the firms that received GVCs in our study.[5] The pairing criteria are listed as follows: when compared with corresponding GVC firms, the matched firms should 1. Did not receive any VC investments at the point when they were selected as the matched firm; 2. Within the same city, same industry and registered in the same year; 3. Have close registered capital (i.e., the difference in between is less than 20%). For each GVC and control firm, we collect other relevant information from the WIND Global Enterprise Database, such as their registration information and copyright work, etc.

Following Fabrizi et al. (2018) and Doblinger et al. (2022), we measure green innovation using patent-based metrics. We obtain the green innovation data by searching the intellectual property information of every funded firm in the China National Intellectual Property Administration (CNIPA) database. According to the definition of green innovation from the World Intellectual Property Organization (WIPO) and the United Nations Framework Convention on Climate Change (UNFCCC), we match the IPC Green Inventory with the standards from the CNIPA. Broadly speaking, green innovation in this study includes eight green technology categories, i.e., alternative energy production, transportation, energy conservation, waste management, agriculture/forestry, administrative, regulatory or design, and nuclear power generation.

After collecting all the available data and matching the control firms, our dataset comprises 11,645 GVC-funded firms and 48,416 matched firms without replacement, leading to our final comprehensive samples of 317,870 firm-year observations. To the best of our knowledge, unlike previous studies that often centred on specific beneficiary groups, this research stands out as the first to utilize an exceptionally comprehensive and up-to-date dataset for Chinese GVCs.

3.2. Method

3.2.1. Difference-in-differences model

To examine the effect of GVC investments on firm green innovation, we adopt the difference-in-differences (DID) model used by Chemmanur et al. (2014) and Bertrand et al. (2004). The DID model, widely used in policy evaluation, follows the principle that is

[1] We collect data from the year 2009 because GVC was officially announced as an industrial policy tool in China in the year 2008 by the files of Guiding Opinions on the Standardized Establishment and Operation of the Government Guiding Fund. The GVC-funded firms in the dataset, including both government master- and sub-funds, did not receive any PVC funds before the sample selection date.

[2] Following the definition of start-ups from the Ministry of Science and Technology China, we define start-ups as those ventures whose ages are less than 5 years since they officially registered, and their registered capital does not exceed CNY 20 million.

[3] To comprehensively examine the full impact of GVCs on green innovation in China, we include publicly traded companies that received GVCs investment in the dataset. The proportion of publicly traded companies accounts for 0.07% of the firm-year observations, which eliminates our concerns of sample selection bias by including publicly traded companies.

[4] Driven by the government investment policy and mainly investing in non-profit-driven projects, the scopes of GVCs in China mainly target seven dimensions, including non-essential public services; infrastructure; housing support; ecosystem and environment; regional development; strategic emerging industries and advanced manufacturing sectors; and entrepreneurial innovation. The seven scopes were established by The Interim Measure for the Administration of Government Venture Capital Funds, released by the Chinese National Development and Reform Commission (NDRC Announcement No. 2800 [2016]).

[5] There are two main commercial databases for VC investment in China, namely Zero2IPO private equity database (https://www.pedata.cn/) and CVSource database (http://www.cvsource.com.cn/). However, both databases are not offering quality data for GVC research. To be specific, these commercial databases, collecting data from news searches on the website, mainly focus on PVCs and cover a small part of GVCs on the official list as well as the firms they funded. In addition, these two databases do not offer information on firms which were not invested by VC previously, which are important components for our control group in the following empirical analyses.

based on a counterfactual framework to evaluate the changes of observed factors in the case of policy occurrence and nonoccurrence. Under the DID framework, an exogenous policy shock divides the sample into two groups – the treatment group subject to policy intervention and the control group – matched to the treatment group but not subject to policy intervention. Specifically, the DID model allows us to control for the differences in green patents between treated and control firms before and after GVC investments so that we can identify the causal effect that reflects the true estimate of the reality. We identify key control variables that could affect GVCs' investment decision-making and are more likely to affect the trend of green innovation in ventures. Accordingly, we construct a panel dataset that captures the green innovation and GVC investments in the following DID model:

$$Y_{it} = a_0 + a_1 GVC_{it} \times AFTER_{it} + a_2 CV_{it} + \mu_{i1} + v_{t1} + \varepsilon_{it1} \tag{1}$$

where the dependent variable Y represents green patents to capture firm green innovativeness, namely *GPAT* (the number of successfully granted green patents). GVC_{it} is a dummy variable taking the value of 1 for firms i that receive GVC in year t.[6] $AFTER_{it}$ is a dummy variable equals 1 if year t is after the year when firms i receive GVC and 0 otherwise. CV_{it} contains control variables that affect enterprise innovation, including enterprise characteristic variables (*AGE*, *CAP*, *CER*, *LAW*, *WRI*, *SOF*, *INS*) and financial development variables, which are defined in Table 1.[7] μ and v are firm-level and time-level fixed effects, respectively, and ε is an error term. In Equation (1), Coefficient a_1 measures the impact of GVC investments on green innovation using the number of patents successfully approved after receiving GVC funding.

To test our second hypotheses, three extended DID models are constructed as follows:

$$GPAT_{it} = b_0 + b_1 GVC_{it} \times AFTER_{it} + b_2 GVC_{it} \times AFTER_{it} \times PVC_{it} + b_3 PVC_{it} + b_4 CV_{it} + \mu_{i2} + v_{t2} + \varepsilon_{it2} \tag{2}$$

$$GPAT_{it} = c_0 + c_1 GVC_{it} \times AFTER_{it} + c_2 GVC_{it} \times AFTER_{it} \times EQU_{it} + c_3 EQU_{it} + c_4 CV_{it} + \mu_{i3} + v_{t3} + \varepsilon_{it3} \tag{3}$$

$$GPAT_{it} = d_0 + d_1 GVC_{it} \times AFTER_{it} + d_2 GVC_{it} \times AFTER_{it} \times BID_{it} + d_3 BID_{it} + d_4 CV_{it} + \mu_{i4} + v_{t4} + \varepsilon_{it4} \tag{4}$$

where PVC_{it} denotes the number of PVC investments obtained by enterprises i in year t. EQU_{it} is the number of times that ventures successfully receive granted loans from other financial institutions using equity pledge financing in year t, on behalf of the accessibility of other financing sources, apart from VC investments. BID_{it} is the number of bidding projects obtained from government agencies, public institutions and state-owned enterprises by enterprises i in year t, representing the ventures' competitive advantages.

Similar to Acharya and Xu (2017) and Hsu et al. (2014), we focus on the signs of b_2, c_2, and d_2, as well as whether they are significantly positive (negative). In the above equations (2)–(4), coefficients b_2 measures whether the subsequent PVC investments attracted by the 'certificate effect' of GVCs amplify the promotion of green innovation, c_2 explores whether the follow-up financing for GVC-certified firms support better green innovation, and d_2 represents whether the competitive advantages in the marketplace of GVC-funded firms lead to better green innovation performance.

3.2.2. Propensity score matching (PSM) method

To minimize the potential endogeneity problem and limit the self-selection bias in previous DID models, we utilize the propensity score matching (PSM) methodology, which is a well-accepted approach to estimate causal treatment effects (Caliendo and Kopeinig, 2008). To select an appropriate counterfactual for GVC-backed firms, the logistic regression model and nearest distance criterion are used for the PSM approach. Specifically, we build the propensity score by a range of firm characteristics with consideration of the following proposed model:

$$GVC_{it} = f_0 + f_1 AGE_{it} + f_2 CAP_{it} + f_3 CER_{it} + f_4 WRIAC_{it} + f_5 SOFAC_{it} + f_6 LAWAC_{it} + \varepsilon_{it5} \tag{5}$$

where *GVC* is a dummy variable with a value of 1 for GVC-funded firms. Control variables are *AGE*, *CAP*, *CER*, *WRIAC*, *SOFAC* and *LAWAC*, where the variable definition is provided in Table 1. ε_{it5} is the error term. In Equation (5), LAWAC is the number of cumulative values of legal proceedings of the firms since establishment, whereas SOFAC refers to the number of cumulative values of software copyrights authorized and WRIAC is the number of cumulative values of copyrights of works authorized. To limit the potential self-selection bias and endogeneity, we calculate the propensity score of each firm based on Equation (5) and adopt one to five ratios to match the control firms within the same city, same industry, and registered in the same year using the closest propensity scores, i.e., 20% deviation of propensity scores. The greater the inclusion of these factors within the set, the higher the likelihood that the estimated treatment effect of GVC investments remains unbiased. In other words, the results will reflect the value added to the investees rather than the selection of good companies through due diligence.[8]

[6] We also included GVC and PVC dummy variables, but the results were omitted due to the large sample sizes in the models.

[7] The models do not include financial data in the DID models due to the characteristics of GVC firms in our dataset. There is no consistent financial data available for our dataset, i.e., start-up ventures account for 56.58% of the entire sample, others include SMEs and publicly traded companies (constituting just 0.07% of the total observations).

[8] We would like to thank the reviewers for providing valuable feedback and sharing their insights on treatment and selection effects.

Table 1
Definition of key variables.

Name	Definition
Panel A: Dependent variable	
$GPAT_{it}$	The number of successfully granted green patents by firm i in year t when they receive GVC
Panel B: Key Independent variables	
GVC_{it}	Dummy variables taking the value of 1 for GVC-funded firms
$AFTER_{it}$	Dummy variables taking the value of 1 if year t is after the year when firm i receives GVC and 0 otherwise
$Start-ups_{it}$	Following the definition of start-ups from the Ministry of Science and Technology China, start-ups are defined as those ventures whose age is less than 5 years since they officially registered, and their registered capital does not exceed CNY 20 million. It equals 1 for start-ups ventures, 0 otherwise.
PVC_{it}	The number of Private venture capital (PVC) investments obtained by firm i in year t
BID_{it}	The number of successful bidding projects obtained from government agencies, public institutions, and state-owned enterprises by firm i in year t
EQU_{it}	The number of times that ventures successfully receive granted loans from other financial institutions using equity pledge financing in year t
Panel C: Control variables	
AGE_{it}	Number of years that the firm operated when they receive GVC funds in year t
CAP_{it}	The registered capital of the firm i in year t, reported in CNY 10,000 units.
LAW_{it}	The number of legal proceedings of firm i in year t
CER_{it}	Equals to 1 if firm i is granted a high-technology firm certificate by the government in year t, 0 otherwise. The renewal of the government high-tech certificate, expiring after three years of the approval date, is subject to new application.
INS_{it}	The number of financial institution outlets in the city where firm i locates in year t
SOF_{it}	The number of software copyright work approved at firm i in year t
WRI_{it}	The number of all other copyright work approved at firm i in year t, excluding software copyright
$LAWAC_{it}$	The number of cumulative values of legal proceedings of the firms since establishment in year t
$WRIAC_{it}$	The number of cumulative values of copyrights of works authorized for firm i in year t
$SOFAC_{it}$	The number of cumulative values of software copyrights authorized for firm i in year t

Table 2
Sample statistics.

Variables	Panel A：Full sample						Panel B：Sub-samples mean values	
	Observations	Min	Median	Mean	Max	Standard deviation	GVC	Matching
GPAT	317,928	0.00	0.00	0.12	220	1.57	0.33	0.07
AGE	317,928	0.00	3.00	4.09	34	4.31	4.11	4.09
CAP	317,928	2.30	6.52	6.42	10.54	1.80	6.66	6.36
LAW	317,928	0.00	0.00	0.38	2491	10.09	0.70	0.30
CER	317,928	0.00	0.00	0.04	1.00	0.20	0.11	0.03
INS	317,870	0.00	2019	2496.50	5706	1554.53	2560.14	2481.09
SOF	317,928	0.00	0.00	0.45	693	2.69	1.19	0.27
WRI	317,928	0.00	0.00	0.25	5000	23.07	0.96	0.08

Panel C:				Panel D:			
By year	Freq.	%	Cum.%	By Age	Freq.	%	Cum.%
2009	201	2	2	0	4607	40	40
2010	274	2	4	1	1808	16	55
2011	320	3	7	2	1276	11	66
2012	309	3	9	3	963	8	74
2013	363	3	13	4	642	6	80
2014	844	7	20	5	412	4	83
2015	1659	14	34	6–10	1173	10	93
2016	2259	19	53	11–19	668	6	99
2017	2717	23	77	20–29	94	1	100
2018	2699	23	100	>30	2	0	100
Total	11,645	100		Total	11,645	100	
Panel E:				Panel F:			
By GVC structure	Freq.	%	Cum.%		Freq.	%	Cum.%
Corporate ventures	7014	60	60	Start-ups	7589	65.17	65.17
Limited partners	2041	18	78	Others	4056	34.83	100
Mixed investment	2590	22	100	Total	11,645	100	
Total	11,645	100					
				Panel G:			
				By tech	Freq.	%	Cum.%
				High-tech	7622	65.45	65.45
				Non-tech	4023	34.54	100
				Total	11,645	100	

Note: This table reports the sample statistics for our dataset. Variable definition is provided in Table 1. Only CAP, the registered capital of firms which is winsorized at 1% and 99% level, is in the logarithm of the capital in CNY 10,000 units. Matching sample criteria is introduced under Section 3.1.

Table 3
Correlation matrix.

	GPAT	AGE	CAP	LAW	CER	INS	SOF	WRI
GPAT	1							
AGE	0.0796***	1						
CAP	0.1186***	0.2544***	1					
LAW	0.0836***	0.2337***	0.2069***	1				
CER	0.1859***	0.1785***	0.1323***	0.1498***	1			
INS	0.008***	−0.0266***	−0.1531***	−0.0267***	−0.001***	1		
SOF	0.1588***	0.086***	0.0775***	0.0558***	0.251***	0.1037***	1	
WRI	0.0301***	0.0194***	0.015***	0.0557***	0.0595***	0.0331***	0.1128***	1

Note: This tables reports the correlation matrix for our dataset with significance levels of ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$, respectively. Variable definition is provided in Table 1. All variables are in logarithm value, except CER.

3.3. Sample statistics

To capture the characteristics of our sample GVC firms, Table 2 reports the sample statistics from different perspectives. Panel A and Panel B show the mean value for the successful green innovation patents (GPAT) is 0.12, with a maximum number of 220. Comparing GPAT between GVC-funded and matching firms, it shows that the mean value of GPAT for GVC-funded firms is 0.33, five times larger than the matching firms (mean value of 0.07). Interestingly, we find that the maximum firm age when they receive GVC funds is 34 years, with a mean value of 4.11 years for GVC firms and 4.09 for the full sample, suggesting that GVC funds play an important role for young firms in seeking finance at their start-up and early growth stage.

Panel C in Table 2 presents the GVC investments by year. It shows an increasing trend of investments since 2009, with a significant increase since 2015 (from 844 GVC investments in 2014 and 1659 investments in 2015, accounting for a 97% increase within a year) and the peak of investment in 2017. Interestingly, Panel D reveals that since 2009, 40% of the GVC invested in start-up firms which operate less than a year, 16% of the GVC funds invested in firms that are one year old, 11% with two years old, leading to a total of 74% of GVC investments in firms that are younger than three years old. It appears that GVC investments in China favour corporate venture structure, accounting for 60%, whilst limited partners are 18% for GVC funds, as shown in Panel E. To provide a snapshot of our GVC firms using other firm characteristics, we find that 65.17% of our GVC-funded ventures are start-ups (Panel F), whose age is less than 5 years old. Not surprisingly, the high-technology sectors attract 65.45% of the GVC investments during 2009–2018 (Panel G). The correlation matrix shows that there is no concern of the dataset (see Table 3).

4. Results and discussion

4.1. Impact of GVCs on green innovation

In this paper, we provide comprehensive evidence of GVCs on green innovation. Results in a DID panel set are reported in Table 4. Model 1 shows that the impact of GVC investments on the innovativeness of green patents is positive and significant at the 1% level. More specifically, the number of granted green patents of GVC ventures increased by 3.8% after receiving GVC investments. Consistent with our hypothesis 1, our findings from a total of 317,870 firm-year observations provide important empirical evidence on the importance of GVC investments in stimulating green innovations advocated by WIPO, UNFCCC, and CNIPA. Our findings remain consistent after applying winsorizing at the 1% and 99% levels for all variables. After controlling for other important variables and year-firm fixed effect, the adjusted R square is 0.488, with a significant p-value for model specification tests.

As a government high-technology certificate (CER) obtained by ventures signifies the greater ability of innovation in GVC firms, it could potentially affect green innovation of the ventures after receiving GVC investments. To explore the impact of CER, we consider the joint effect of GVC investments and CER. Model 2 in Table 4 suggests that when ventures receive GVC investments and government-certified high-technology qualification, it significantly increases the number of patents in green innovation, with a coefficient of 0.058 for the interaction term. In other words, a 1% rise in the number of high-technology firms certified by the government, following investments from GVCs, corresponds to a 5.8% increase in green innovation levels compared to their non-certified counterparts among high-tech companies. Interestingly, the joint effect of GVC investments and CER meanwhile leads to a significant change in the impact of GVC investments on green innovation. The coefficient of the impact of GVCs on GPAT increases from 0.038 in Model 1 to 0.098 in Model 2, which indicates a 9.8% increase in granted green patents for ventures after they successfully receive GVC investments. The adjusted R square increases to 0.771 in Model 2, a notable rise from Model 1.

In Model 3, Table 4, we examine the effects of GVC investments in start-ups. We set up a binary variable that equals 1 for ventures that meet the criteria as start-ups, i.e., whose ages are less than 5 years since they officially registered, and their registered capital does not exceed CNY 20 million, 0 otherwise for all other SMEs and public-traded companies in our samples. The result shows that, although GVC investments significantly increase green innovation, this stimulation shrinks when the GVC-funded ventures are start-ups. In economic terms, if a start-up receives GVC funds, it increases the number of granted green patents by 1.8% (5.8% minus 4%), compared with 3.8% in model 1 for the whole sample. Our result is contrary to the results reported by Dong et al. (2021) who provide evidence that GVCs negatively affect green innovation for 185 environmentally friendly firms in China.

Start-ups tend to signify great potential for growth and innovation which makes them more attractive to VCs. However, at the initial

Table 4
Impacts of GVCs on green innovation.

Variables	(1) DID	(2) DID	(3) DID	(4) DID	(5) Logit
	GVCs	CER	Start-ups	High-tech	GVCs
GVC × AFTER	0.038***	0.098***	0.058***	0.017***	1.167***
	(7.852)	(13.131)	(7.244)	(2.607)	(27.700)
GVC × AFTER × CER		0.058***			
		(2.979)			
GVC × AFTER × Start-ups			−0.040***		
			(-4.283)		
GVC × AFTER × High-tech				0.031***	
				(3.378)	
AGE	0.010***	0.010***	0.012***	0.009***	0.432***
	(5.396)	(3.172)	(6.533)	(5.262)	(16.899)
CAP	0.006***	0.006***	0.006***	0.006***	0.382***
	(8.221)	(4.872)	(8.077)	(8.231)	(31.136)
LAW	0.009***	0.048***	0.009***	0.010***	0.002
	(4.063)	(13.263)	(3.864)	(4.165)	(0.098)
CER	0.081***	0.301***	0.080***	0.080***	1.048***
	(11.783)	−23.466	(11.673)	(11.654)	(22.584)
INS	−0.003	−0.020	−0.003	−0.003	0.065***
	(-0.357)	(-0.979)	(-0.359)	(-0.283)	(2.663)
SOF	0.038***	0.028***	0.038***	0.038***	0.821***
	(15.685)	(10.176)	(15.794)	(15.588)	(39.682)
WRI	0.019***	0.009	0.019***	0.019***	0.216***
	(3.899)	(1.513)	(3.911)	(3.962)	(3.993)
Constant	−0.014	0.065	−0.011	−0.019	−9.809***
	(-0.202)	(0.440)	(-0.167)	(-0.276)	(-42.573)
Observations	317,870	317,870	317,870	317,870	317,870
Year effect	Y	Y	Y	Y	Y
Firm effect	Y	Y	Y	Y	N
Adjusted R^2	0.488	0.771	0.488	0.488	NA

Note: This table reports the impact of GVC investments on green innovation GPAT using DID models (Model 1–4) and logit model (Model 5). Variable definition is provided in Table 1. All variables are in logarithm value, except CER. Year fixed effect and firm fixed effect are controlled whereas clustered t statistics are provided in parentheses with significance levels of ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$, respectively.

stage, it requires large capital outlay to develop and scale up the ventures quickly. Whilst green innovation requires long-term and large amounts of investments, start-ups might struggle with green innovation or allocate their capital in other operation areas. The constraints of cash flow shortage might lead GVC managers to focus on short-term investment, reducing loss of start-ups, rather than long-term green innovation investments. Another possible reason is that 60% of the GVC investments in our samples are operated in corporate venture structures. The bureaucratic corporate governance structure of GVCs and potential politically driven decision-making might result in less efficiency in promoting green innovation. Meanwhile, GVCs are normally managed by government officers, which results in less innovation and lack of flexibility. The underperform might be caused by the lower engagement of GVCs in coaching and value-adding activities in those ventures (Colombo et al., 2016). Hence, our findings provide invaluable insights to policymakers on the effects of GVC investments on green innovation in start-ups, suggesting that GVCs shall establish efficient mechanisms to monitor green innovation and develop effective green innovation support in start-ups.

A natural question we ask next is whether high-technology firms tend to be more innovative with green patents. Model 4 in Table 4 supports our expectations. Result shows that the effects of GVC investments on high-technology ventures is positive and significant, with a coefficient of 0.031 at the 1% significance level. From an economic perspective, high-tech firms are connected with a 3.1% rise in enhancing the influence of GVCs on green innovation. We further examine the impact of GVC investments on green patents using the logit model. Model 5 reports the logit results after controlling the year fixed effect. Results show that ventures that successfully receive GVC investments are more likely to grant green patent applications, with a significant and positive coefficient of 1.167. The economic meaning of the logit model provides supporting evidence that is consistent with the results in Model 1.

Across Model 1–5, we find that the age of the firm, the registered capital, the number of government qualification certificates and the number of software copyrights authorized at the ventures present significant and positive impacts on green patents. Interestingly, whilst the number of financial institutions in the city shows an insignificant impact on green innovation (Model 1–4), results show a positive and significant impact of the number of financial institutions on the likelihood of receiving granted green innovation for ventures in Model 5. In other words, if the ventures are located in a city with more financial institutions, they are more likely to receive more granted green innovation.

4.1.1. Results from the PSM approach

To control for the potential endogeneity problem and limit the self-selection bias in DID settings, we turn our augmented model to the PSM approach using the nearest distance criterion. The PSM technique allows us to disentangle the impact of GVC investments on green innovation according to the observable firm characteristics for treatment and control firms. After using the closest propensity

Table 5
Results from propensity score matching.

Variables	Panel A : Logit on GVCs		Panel B : Parallel Assumption Test			Panel C: DID models after the PSM	
	Pre-matching	Post-matching	Variables	Coefficient	t-statistics	Variables	GPAT
AGE	−0.300***	0.004	GOV × Before4	0.008	(0.392)	GVC × AFTER	0.020***
	(-20.560)	(0.156)	GOV × Before3	0.020	(0.902)		(2.922)
CAP	0.073***	0.015	GOV × Before2	0.037	(1.483)	AGE	0.024***
	(11.490)	(1.589)	GOV × Before1	0.036	(1.442)		(5.107)
LAW	0.182***	−0.072	GOV × Current	0.059**	(2.359)	CAP	0.010***
	(7.164)	(-1.190)	GOV × After1	0.067**	(2.576)		(3.810)
CER	0.955***	−0.030	GOV × After2	0.062**	(2.348)	LAW	0.015***
	(16.648)	(-0.192)	GOV × After3	0.065**	(2.416)		(2.707)
SOF	0.723***	0.000	GOV × After4	0.077***	(2.602)	CER	0.072***
	(48.103)	(0.002)	AGE	0.016***	(3.058)		(5.096)
WRI	0.854***	0.184	CAP	0.006**	(2.484)	INS	0.020
	(16.713)	(0.999)	CER	0.062***	(3.535)		(0.670)
Constant	−1.947***	−0.095	INS	0.023	(0.728)	SOF	0.039***
	(-46.639)	(-1.528)	SOF	0.034***	(6.505)		(7.946)
Observations	11645	7142	WRI	0.001	(0.120)	WRI	0.018*
Pseudo R^2	0.0761	0.0002	Constant	−0.214	(-0.917)		(1.874)
			Observations	53,146		Constant	−0.201
			Adjusted R2	0.487			(-0.955)
						Observations	68,663
						Year effect	Y
						Firm effect	Y
						Adjusted R^2	0.485

Note: Panel A and B reports the diagnosis for Propensity Score Matching (PSM). Panel C reports the impact of GVC investments on green innovation using the DID model after the PSM. Variable definition is provided in Table 1. All variables are in logarithm value, except CER. Year fixed effect and firm fixed effect are controlled whereas clustered t statistics are provided in parentheses with significance levels of ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$, respectively.

scores with a one to five ratio to match the control firms in the same city, same industry, and registered in the same year, we successfully matched 7142 GVC-funded firms with their control firms, resulting in a matching rate of 61 percent. To assess whether the propensity score model has been adequately specified, we perform two different diagnostic tests as reported in Table 5. Panel A in Table 5 compares the results of logit regression between pre- and post-matching GVC firms. It shows that firm characteristics significantly affect the GVC investments in the treated group before matching. However, these firm characteristics are no longer significant after matching with control firms. It is noticeable that the Pseudo R^2 for post-matching treated firms is 0.02%, reduced from 7.61% from the pre-matching model. Panel B investigates the parallel trend assumption of treatment and control firms. It demonstrates a significant difference between our treatment and control firms in the level of firms' green innovation after receiving investments from GVCs, whilst no significant difference exists before GVC investments. With an adjusted R^2 of 48.7%, it verifies the parallel trends of matched samples, indicating that the DID setting is appropriate for the level of analyses in this study.

According to the results of PSM models, we re-estimate our equation (1) to explore the relationship between the number of granted green patents and GVC investments after PSM consideration. Panel C shows that the coefficient of GOV and AFTER is still significantly positive at the 1% level, with a value of 0.02. Hence, after controlling for the potential endogeneity and self-selection bias problems by adopting the PSM method, our key findings remain unchanged–- GVC investments significantly foster green innovation for their portfolio firms. Results for other control variables are consistent with our findings in Table 4.

4.2. *The 'certification effect' of GVCs on green innovation*

We further examine the potential mechanisms of GVCs on firms' green innovation by investigating whether this stimulation effect can be magnified via the 'certification effect', i.e., the increased financing sources and subsequent competitive advantages. Specifically, we explore the impacts of the following-up PVC investments, granted loans from financial institutions, and the number of bidding projects obtained after firms receive GVC investments.

Table 6 reports the results of 'certification effect' with the number of granted green patents as a dependent variable. Like Acharya and Xu (2017) and Hsu et al. (2014), we examine the interaction terms of GVC, AFTER, and PVC to explore the impact of GVCs on attracting PVC investments. In economic terms, PVCs do not have a significant positive impact on green innovation. However, our results report a positive and significant coefficient of 0.012 at the 10% level, indicating that the subsequent PVC investments allured by GVCs will further foster green innovation. Our findings support our hypothesis on the advantages of the 'certification effect', suggesting that following-up PVC investments in GVC-certified ventures amplify the positive effects of GVCs on green innovation.

We further examine whether other financial sources apart from the PVC investments can boost green innovation through the 'certification effect'. In detail, the effects of the following-up loans from financial institutions, which play an important role in green innovation, are examined in Model 2, Table 6. Results show an insignificant coefficient for the joint effects of GVC investments and the granted loans using equity pledge financing by the ventures. However, we find that ventures receiving more loans via equity pledge

Table 6
The certification effects of GVCs.

Variables	(1)	(2)	(3)
	PVC	EQU	BID
GVC × AFTER	0.032***	0.036***	0.032***
	(6.180)	(7.397)	(6.595)
GVC × AFTER × PVC	0.012*		
	(1.874)		
PVC	0.004		
	(0.881)		
GVC × AFTER × BID			0.059***
			(3.831)
BID			0.020***
			(3.709)
GVC × AFTER × EQU		0.021	
		(1.516)	
EQU		0.012*	
		(1.919)	
AGE	0.010***	0.010***	0.010***
	(5.554)	(5.377)	(5.903)
CAP	0.006***	0.006***	0.006***
	(8.048)	(8.193)	(8.124)
LAW	0.010***	0.009***	0.009***
	(4.161)	(3.867)	(3.830)
CER	0.081***	0.080***	0.078***
	(11.818)	(11.718)	(11.308)
INS	−0.003	−0.003	−0.003
	(-0.354)	(-0.331)	(-0.359)
SOF	0.038***	0.038***	0.037***
	(15.575)	(15.698)	(15.246)
WRI	0.018***	0.018***	0.019***
	(3.848)	(3.874)	(3.916)
Constant	−0.013	−0.015	−0.012
	(-0.195)	(-0.223)	(-0.178)
Observations	317,870	317,870	317,870
Year effect	Y	Y	Y
Firm effect	Y	Y	Y
Adjust-R^2	0.488	0.488	0.489

Note: This table reports the certification effect of GVC investments on green innovation GPAT using DID models. Variable definition is provided in Table 1. All variables are in logarithm value, except CER. Year fixed effect and firm fixed effect are controlled whereas clustered t statistics are provided in parentheses with significance levels of ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$, respectively.

financing produce more successful green patents. We then ask the question whether the competitive advantages in the marketplace of GVC-funded ventures help to stimulate green innovation. Model 3 shows the joint effects of GVCs and the bidding projects obtained by the ventures from government agencies, public institutions, and state-owned enterprises. Results confirm a prevailing position of competitive advantages of GVC-backed ventures in promoting green innovation. We find positive effects of subsequent acquisitions of bidding projects and green innovation, with a significant coefficient of 0.059 at the 1% level.

Our results show that companies funded by GVCs attract subsequent financing sources and the resulting competitive advantages amplify green innovation in the marketplace through the 'certification effect'. This effect alleviates the shortage of operating cash flow for ventures, promote long-term growth, and stimulates green innovation. Interestingly, results show that other public investments from government agencies, public institutions, and state-owned enterprises significantly increase the number of green patents. These important findings offer insights to policymakers and managers on how to develop mechanisms to advance green innovation in their own regions and countries.

4.3. Impact of different GVC structures on green innovation

Gaining increasing recognition in the drive to foster green innovation, Chinese GVCs are typically supervised and overseen by government entities (Dong et al., 2021). To examine the diverse structural aspects of GVCs in China, we explore the impact of GVCs organized under the corporate venture framework and those structured as limited partnerships. Results in Panel A, Table 7 report the results for different GVC structures. We find that the effects of GVCs structured in both corporate ventures and limited partners are significant and positive at the 1% level. Interestingly, contrary to our hypothesis, results exhibit that limited partner structure shows stronger effects on promoting firms' green innovation, with a significant coefficient of 0.049 for limited partners, compared with a coefficient of 0.031 for corporate venture structure. Considering that limited partners only account for 18% of all GVC firms, our results provide valuable empirical evidence of different GVC structures on green innovation, which is beneficial to policymakers and decision-makers when they consider strategy in limited partner GVCs in promoting green innovation.

Table 7
DID models for different GVC structures.

Variables	Panel A: GPAT		Panel B: Fisher's permutation test	
	GVCs structured in corporate ventures	GVCs structured in limited partnerships	a_0-a_1	p-value
GVC × AFTER	0.031***	0.049***	−0.018	0.087
	(5.269)	(3.929)		
AGE	0.007***	0.011***	−0.004	0.19
	(2.960)	(2.853)		
CAP	0.007***	0.005**	0.002	0.188
	(6.823)	(2.544)		
LAW	0.007**	0.006	0.001	0.432
	(2.503)	(1.310)		
CER	0.077***	0.081***	−0.004	0.469
	(9.085)	(4.325)		
INS	−0.008	0.030	−0.038	0.049
	(-0.776)	(1.227)		
SOF	0.039***	0.025***	0.014	0.018
	(13.145)	(4.357)		
WRI	0.017***	0.017	0	0.47
	(2.814)	(1.643)		
Constant	0.021	−0.242	0.263	0.06
	(0.264)	(-1.396)		
Observations	199,644	52,762		
Year effect	Y	Y		
Firm effect	Y	Y		
Adjusted R2	0.484	0.483		

Note: This table reports the impact of the structure of GVCs on green innovation GPAT. Variable definition is provided in Table 1. All variables are in logarithm value, except CER. Year fixed effect and firm fixed effect are controlled whereas clustered t statistics are provided in parentheses with significance levels of ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$, respectively.

Panel B in Table 7 reports the differences between the coefficients of the two groups. The difference between GVCs structured in limited partners and corporate ventures structure on green innovation is 0.018, significant at the 10% level, further confirming that GVCs in limited partnerships are more effective in promoting firms' green innovation when compared with corporate ventures structure. The advantage of limited partnerships could stem from the better performance of limited partners in identifying and incentivizing managers (Levin and Tadelis, 2005), allowing investors to actively participate in GVC investments, reducing the costs from the agency problems (Sahlman, 1990), hence their capacity for risk control and value creation can be improved, which is critical

Table 8
DID models for different geographic proximities.

Variables	Panel A：regression in sub-groups		Panel B：Fisher's permutation test	
	Intra-province/city	Inter-province/city	a_0-a_1	p-value
GVC × AFTER	0.044***	0.029***	0.016	0.04
	(6.872)	(3.518)		
AGE	0.007***	0.010***	−0.003	0.188
	(2.886)	(3.173)		
CAP	0.006***	0.007***	0	0.389
	(5.776)	(5.554)		
LAW	0.012***	0.004	0.008	0.01
	(4.015)	(1.055)		
CER	0.072***	0.090***	−0.019	0.07
	(7.939)	(7.685)		
INS	−0.006	0.006	−0.012	0.235
	(-0.625)	(0.267)		
SOF	0.039***	0.036***	0.003	0.262
	(11.722)	(9.716)		
WRI	0.017***	0.019**	−0.002	0.385
	(2.625)	(2.231)		
Constant	0.008	−0.079	0.087	0.232
	(0.104)	(-0.515)		
Observations	179,024	110,535		
Year effect	Y	Y		
Firm effect	Y	Y		
Adjusted R^2	0.472	0.497		

Note: This table reports the impact of GVC investments on green innovation GPAT for different geographic proximities using DID models. Variable definition is provided in Table 1. All variables are in logarithm value, except CER. Year fixed effect and firm fixed effect are controlled whereas clustered t statistics are provided in parentheses with significance levels of ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$, respectively.

and beneficial for green innovation of funded firms.

5. Robustness tests

5.1. Impact of geographic proximity on green innovation

Evidence suggests that GVCs may support localised start-ups in consideration of regional economic development (Alperovych et al., 2020; Colombo et al., 2016). Among various discussions, knowledge spillover theory has been identified as a key factor to explain why GVCs support innovation. According to Griliches (1992), the market fails to price the R&D spillovers of innovation and ignores the related social value of start-ups. GVCs, in this regard, are designed to address this market failure (Lerner, 2000). Furthermore, knowledge spillovers, being called 'localized knowledge spillovers' (Breschi and Lissoni, 2001), have a strong propensity to be bonded in space, suggesting that the positive externalities of innovation mainly benefit companies in local regions.

As geographic proximity between investors and investees is generally considered beneficial due to the improvement of monitoring efficiency (Bernstein et al., 2016), we explore whether geographic proximity between GVCs and GVC-funded firms affect the effectiveness of GVCs in promoting firms' green innovation. Specifically, we divide our samples into two sub-groups, intra-province/city and inter-province/city based on whether GVCs and the invested firms are in the same province/city. Panel A in Table 8 reports the results based on geographic proximities. Results show that GVC investments in both intra-province/city and inter-province/city present a significantly positive effect at the 1% level. We find that intra-province/city firms perform better in green innovation after the investments from GVCs, compared with inter-province/city firms, with coefficients of 0.044 and 0.029, respectively. These results suggest that geographic proximity between GVCs and the beneficiaries improves the effect of green innovation. In other words, the closer the GVCs and ventures, the better effect of GVCs in promoting green innovation of the ventures.

5.2. The effect of GVCs on the quality of green innovation

To the best of our knowledge, there is little empirical evidence of GVCs on the quality of green innovations in the portfolio firms. To provide more insightful results, we explore the impact of GVCs on the quality of green innovation, proxied by the patent citation which could capture the economic 'values' of patents. Following our Equation (1), the dependent variable *Y* now represents the quality of green patents to capture firm green innovativeness, namely *GPATCITE* (the number of green patent citations), *GPATCLAIM* (the number of green patent application claims), and *GPATIPC* (the number of green patent international classification codes). To be specific, GPATCITE is the number of granted patent citations by firm i in year t; GPATCLAIM represents the number of claims listed in green patent applications by firm i in year t; and GPATIPC indicates the number of Green Patent International Classification Codes by firm i in year t. The three different dimensions measure the quality of green innovation from different dimensions.

Table 9
Impacts of GVCs on the quality of green innovation.

Variables	(1)	(2)	(3)
	GPATCITE	GPATCLAIM	GPATIPC
GVC × AFTER	0.012***	0.068***	0.036***
	(2.688)	(9.560)	(8.712)
AGE	0.017***	0.016***	0.009***
	(10.949)	(6.624)	(6.364)
CAP	0.004***	0.009***	0.005***
	(6.142)	(8.190)	(8.308)
LAW	−0.007***	0.009***	0.005***
	(-3.798)	(3.298)	(3.061)
CER	−0.016***	0.129***	0.074***
	(-2.674)	(13.434)	(13.069)
INS	0.011	0.003	0.003
	(1.211)	(0.242)	(0.361)
SOF	0.032***	0.063***	0.034***
	(14.281)	(18.109)	(17.489)
WRI	0.014***	0.029***	0.016***
	(3.181)	(3.988)	(3.922)
Constant	−0.091	−0.072	−0.048
	(-1.369)	(-0.753)	(-0.794)
Observations	317,870	317,870	317,870
Year effect	Y	Y	Y
Firm effect	Y	Y	Y
Adjusted R^2	0.354	0.418	0.398

Note: This table reports the impact of GVC investments on the quality of green innovation using DID models. Variable definition is provided in Table 1. All variables are in logarithm value, except CER. Year fixed effect and firm fixed effect are controlled whereas clustered t statistics are provided in parentheses with significance levels of ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$, respectively.

Table 10
Additional robustness checks using DID models.

Variables	(1)	(2)	(3)	(4)	(5)
	With one lag period	With more than 20% master funds	With GVC for business	GVCs without publicly traded companies	Control for national disasters
GVC × AFTER	0.020***	0.043***	0.043***	0.039***	0.130**
	(3.309)	(5.077)	(7.444)	(8.223)	(2.153)
GVC × AFTER × DIS					−0.011
					(-1.523)
DIS					0.144
					(1.096)
AGE	0.001	0.012***	0.011***	0.011***	0.010***
	(0.238)	(3.981)	(5.280)	(6.177)	(5.369)
CAP	0.007***	0.006***	0.007***	0.006***	0.006***
	(7.105)	(4.206)	(7.871)	(8.055)	(8.237)
LAW	0.006**	0.004	0.011***	0.007***	0.009***
	(2.109)	(1.035)	(3.736)	(3.307)	(4.023)
CER	0.054***	0.073***	0.075***	0.078***	0.081***
	(6.974)	(6.663)	(9.707)	(11.423)	(11.734)
INS	−0.003	−0.020*	0.001	−0.003	−0.003
	(-0.318)	(-1.816)	(0.052)	(-0.334)	(-0.349)
SOF	0.021***	0.043***	0.036***	0.036***	0.038***
	(7.497)	(9.191)	(13.561)	(15.651)	(15.683)
WRI	0.009*	0.011	0.020***	0.020***	0.019***
	(1.713)	(1.427)	(3.664)	(4.052)	(3.893)
Constant	−0.003	0.109	−0.049	−0.015	−1.142
	(-0.037)	(1.416)	(-0.470)	(-0.212)	(-1.151)
Observations	257,817	99,832	238,049	314,438	317,870
Year effect	Y	Y	Y	Y	Y
Firm effect	Y	Y	Y	Y	Y
Adjusted R^2	0.532	0.500	0.478	0.478	0.488

Note: This table reports several robustness checks on the impact of GVC investments on green innovation GPAT using DID models. Variable definition is provided in Table 1. DIS measures the natural disasters data, reported as the annual natural disaster losses in hundred millions CNY, mainly including flood, typhoon, drought, earthquake, and geological disaster, as well as other disasters like wildfire, wind and hail, extreme temperature, and snow disaster in China. All variables are in logarithm value, except CER. Year fixed effect and firm fixed effect are controlled whereas clustered t statistics are provided in parentheses with significance levels of ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$, respectively.

Models 1 to 3 in Table 9 show that the effects of GVCs on the quality of green innovation are consistently positive and significant at the 1% level. Model 1 indicates that firms receiving GVC investments increase their green patent citations by 1.2%. Interestingly, Model 2 suggests that the number of green patent application claims for GVCs firms significantly increase by 6.8%, whilst the number of Green Patent International Classification Codes rise by 3.6% after receiving investments from GVCs. These results further prove the positive impacts of GVC investment on green innovation from various quality dimensions.

5.3. Additional robustness results

According to the characteristics of both green innovation and GVCs, we further conduct five additional robustness checks by re-estimating Equation (1). First, given that there can be a lag effect, we use the data of granted green patents with a lag period. Second, we divide GVC into master funds and sub-funds by retaining the firms invested by the sub-funds with more than 20% of the proportion of the master funds. This approach is on the consideration because it is common for GVC to invest indirectly in the form of master-funds and thereby exert leverage effects. As a result, we control the investment ratio of GVC master-funds to 20% to verify our analysis. Third, we further extend our analysis based on the types of GVCs, including funds for business and new ventures, industrial development, and public service in China. We therefore consider only GVCs for business, whose goals could fit more in promoting green innovation. Models 1 to 3 in Table 10 report our empirical results for these robustness checks. The coefficients in all three models are statistically significant at the 1% level. Because the impacts of GVC investments on green innovation in all three models are consistent with our previous results, the additional results further prove that the impacts of GVCs on firms' green innovation are strong and robust in China.

Next, as the number of publicly traded companies only accounts for 0.07% of the firm-year observations, there is no serious concern of sample selection bias because publicly traded companies generally being identified as the most successful exit for venture capitalists. However, exploring the effect of GVCs on privately held companies adds an intriguing dimension to our results, completing the overall perspective. Model 4 in Table 10 removes all publicly traded companies that received GVC investments. Results show materialized consistent results as reported in Table 4. Notably, in Table 10, the coefficient after GVC investments rises to 0.039 with 1% significance level after excluding publicly traded companies, compared to the coefficient of 0.038 in Table 4.

Finally, as recent studies argue that natural disasters have significant impact on sustainable financial products by increasing investors' preference in sustainable investment (Fiordelisi et al., 2024), we examine the impact of natural disasters in China on green innovation.[9] We collect natural disaster data from the National Development and Reform Commission in China. Natural disasters data captures the annual natural disaster losses in hundred million Chinese currency, mainly including flood, typhoon, drought, earthquake, and geological disaster, as well as other disasters like wildfire, wind and hail, extreme temperature, and snow disaster in China. Results are reported in Model 5, Table 10. Interestingly, we find an increased effect of GVC investments on green innovation after considering the natural disasters - the coefficient increases from 0.038 (Table 4) to 0.13 (at the 5% significance level) in Model 5, Table 10. However, the effects of natural disasters are reported as statistically insignificant. Hence, our findings suggest that natural disasters in China do not significantly affect green innovation.

6. Conclusion

In this paper, we provide robust empirical results of the impact of GVC investments on green innovation in DID and PSM panel settings using big data evidence. Policymakers around the world have a strong motivation to advance the creative power of capital to drive green innovation when dealing with worldwide environmental problems (Faria and Barbosa, 2014; Lerner, 2002; Soleimani Dahaj and Cozzarin, 2019). GVCs, with the aim of bridging equity gaps in VC markets, could offer potentially effective mechanisms to spur firm green innovation. However, despite the continuously growing GVC investments globally, few studies have empirically investigated the real effects of GVCs on green innovation.

Our paper sheds light on the effects of GVCs on green innovation. We create a comprehensive and unique big dataset to examine the impact of GVCs on green innovation in China between 2009 and 2018. We find consistent results of significant and positive effects of GVC investments on green innovation, strongly supporting our hypothesis that GVCs significantly promote green innovation in their funded ventures. An interesting result shows that the positive effect of GVC investments on green innovation is smaller in start-ups. Our findings show that following-up financing sources and competitive advantages of GVC-funded ventures magnify the positive effect on green innovation, which verified the 'certification effect'. Our third hypothesis proposes that GVCs in corporate venture capitalists structure shall encourage more green innovation than those structured in limited partnership. Contrary to our hypothesis, our findings suggest that limited partnership structure stimulates green innovation better than GVCs structured in corporate venture capitalist. In our robustness checking, we find that GVC investments in intra-province/city tend to increase green innovation proxied by the number of green innovation patents. Meanwhile, firms receiving GVC investments increase the quality of their green innovation significantly.

We contribute to the current debate on the effectiveness of GVCs in nurturing firms' innovativeness by providing valuable empirical evidence on how GVCs effectively promote green innovation and sustainable growth. While some studies show that government intervention leads to a negative influence on green innovation for 185 environmentally friendly firms in China (Dong et al., 2021), we provide insights using a big dataset consisting 317,870 firm-year observations from 2009 to 2018 by including all start-ups, SMEs and publicly traded firms in our analyses. Our results consistently show that GVCs play a significant and important role in advancing green innovation. We would recommend that governments around the world continue developing policy-oriented green financial markets, unleashing the innovative power of capital to tackle climate change and environmental problems, particularly to grow GVC investments in green innovation. Furthermore, our finding reports a smaller but significant effect of GVCs on green innovation in start-ups. It is recommended that policymakers shall pay greater attention to GVC investments with the aim to promote green innovation in start-ups. Therefore, we urge policymakers to detect the strength and weaknesses of GVCs before investing in start-ups and strive to develop effective GVC support and efficient mechanisms of monitoring and evaluation when promoting green innovation in start-ups. Last but not least, with regards to building the strategy for GVCs, a limited partnership structure could work more effectively than a corporate venture structure in stimulating green innovation. The advantages of limited partnership in tax transparency, organisational flexibility, and limited liability might help to magnify the positive impact of GVCs.

Declaration

This work was supported by the China Scholarship Council [Grant number 202006200010, 2020]; the National Social Science Foundation of China [Grant number 22STA040, 2022. The authors have no competing interests to declare that are relevant to the content of this article.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Jiayin Meng reports financial support was provided by China Scholarship Council (CSC) under the CSC Grant No.202006200010. Yuchen Li receives support under the Academic Theme 'Strategic Research on Water Financial Service System' from the National Social Science Foundation of China (Grant No.22STA040).

[9] We would like to thank the reviewer for their constructive feedback on the impact of natural disaster on green innovation.

Acknowledgement

We would like to thank the editors and reviewers for their invaluable feedback and detailed comments, which have greatly enhanced the overall quality of our paper.

References

Acharya, A., & Xu, Z. (2017). Financial dependence and innovation: The case of public versus private firms. *Journal of Financial Economics, 124*, 223–243.
Alperovych, Y., Groh, A., & Quas, A. (2020). Bridging the equity gap for young innovative companies: The design of effective government venture capital fund programs. *Research Policy, 49*, Article 104051.
Alperovych, Y., Hubner, G., & Lobet, F. (2015). How does governmental versus private venture capital backing affect a firm's efficiency? Evidence from Belgium. *Journal of Business Venturing, 30*, 508–525.
Amore, M. D., & Bennedsen, M. (2016). Corporate governance and green innovation. *Journal of Environmental Economics and Management, 75*, 54–72.
Armour, J., & Cumming, D. (2006). The legislative road to Silicon Valley. *Oxford Economic Papers, 58*, 596–635.
Bai, Y., Song, S., Jiao, J., & Yang, R. (2019). The impacts of government R&D subsidies on green innovation: Evidence from Chinese energy-intensive firms. *Journal of Cleaner Production, 233*, 819–829.
Bakhtiari, S. (2021). Government financial assistance as catalyst for private financing. *International Review of Economics & Finance, 72*, 59–78.
Bernauer, T., Engel, S., Kammerer, D., & Sejas Nogareda, J. (2007). Explaining green innovation: Ten years after porter's win-win proposition: How to study the effects of regulation on corporate environmental innovation? *Politische Vierteljahresschrift, 39*, 323–341.
Bernstein, S., Giroud, X., & Townsend, R. R. (2016). The impact of venture capital monitoring. *The Journal of Finance, 71*, 1591–1622.
Bertoni, F., Colombo, M. G., & Quas, A. (2015). The patterns of venture capital investment in Europe. *Small Business Economics, 45*, 543–560.
Bertoni, F., & Tykvová, T. (2015). Does governmental venture capital spur invention and innovation? Evidence from young European biotech companies. *Research Policy, 44*, 925–935.
Bertrand, M., Duflo, E., & Mullainathan, S. (2004). How much should we trust differences-in-differences estimates? *Quarterly Journal of Economics, 119*, 249–275.
Breschi, S., & Lissoni, F. (2001). Localised knowledge spillovers vs. innovative milieux: Knowledge "tacitness" reconsidered. *Papers in Regional Science, 80*, 255–273.
Brunnermeier, S. B., & Cohen, M. A. (2003). Determinants of environmental innovation in US manufacturing industries. *Journal of Environmental Economics and Management, 45*, 278–293.
Bürer, M. J., & Wüstenhagen, R. (2009). Which renewable energy policy is a venture capitalist's best friend? Empirical evidence from a survey of international cleantech investors. *Energy Policy, 37*, 4997–5006.
Caliendo, M., & Kopeinig, S. (2008). Some practical guidance for the implementation of propensity score matching. *Journal of Economic Surveys, 22*, 31–72.
Castellacci, F., & Lie, C. M. (2017). A taxonomy of green innovators: Empirical evidence from South Korea. *Journal of Cleaner Production, 143*, 1036–1047.
Chang, C.-H. (2011). The influence of corporate environmental ethics on competitive advantage: The mediation role of green innovation. *Journal of Business Ethics, 104*, 361–370.
Chemmanur, T. J., Loutskina, E., & Tian, X. (2014). Corporate venture capital, value creation, and innovation. *Review of Financial Studies, 27*, 2434–2473.
Chen, Y.-S. (2008). The driver of green innovation and green image – green core competence. *Journal of Business Ethics, 81*, 531–543.
Colombo, M. G., Cumming, D. J., & Vismara, S. (2016). Governmental venture capital for innovative young firms. *The Journal of Technology Transfer, 41*, 10–24.
Criscuolo, C., & Menon, C. (2015). Environmental policies and risk finance in the green sector: Cross-country evidence. *Energy Policy, 83*, 38–56.
Cuerva, M. C., Triguero-Cano, Á., & CóRCOLES, D. (2014). Drivers of green and non-green innovation: Empirical evidence in low-tech SMEs. *Journal of Cleaner Production, 68*, 104–113.
Cumming, D. J. (2005). Capital structure in venture finance. *Journal of Corporate Finance, 11*, 550–585.
Cumming, D. J. (2007). Government policy towards entrepreneurial finance: Innovation investment funds. Capital structure in venture finance. *Journal of Business Venturing, 22*, 193–235.
Cumming, D., Fleming, G., & Schwienbacher, A. (2007). The structure of venture capital funds. *Handbook of research on venture capital* (pp. 155–176).
Cumming, D. J., Grilli, L., & Murtinu, S. (2017). Governmental and independent venture capital investments in europe: A firm-level performance analysis. *Journal of Corporate Finance, 42*, 439–459.
Cumming, D. J., & Johan, S. (2008). Information asymmetries, agency costs and venture capital exit outcomes. *Venture Capital, 10*, 197–231.
Cumming, D. J., & Macintosh, J. G. (2006). Crowding out private equity: Canadian evidence. *Journal of Business Venturing, 21*, 569–609.
Del-Palacio, I., Zhang, X. T., & Sole, F. (2012). The capital gap for small technology companies: Public venture capital to the rescue? *Small Business Economics, 38*, 283–301.
Denis, D. J. (2004). Entrepreneurial finance: An overview of the issues and evidence. *Journal of Corporate Finance, 10*, 301–326.
Devenow, A., & Welch, I. (1996). Rational herding in financial economics. *European Economic Review, 40*, 603–615.
Ding, J., Lu, Z., & Yu, C. H. (2022). Environmental information disclosure and firms' green innovation: Evidence from China. *International Review of Economics & Finance, 81*, 147–159.
Doblinger, C., Surana, K., Li, D., Hultman, N., & AnadóN, L. D. (2022). How do global manufacturing shifts affect long-term clean energy innovation? A study of wind energy suppliers. *Research Policy, 51*, Article 104558.
Dong, W., Li, Y., Lv, X., & Yu, C. (2021). How does venture capital spur the innovation of environmentally friendly firms? Evidence from China. *Energy Economics, 103*, Article 105582.
Fabrizi, A., Guarini, G., & Meliciani, V. (2018). Green patents, regulatory policies and research network policies. *Research Policy, 47*, 1018–1031.
Faria, A. P., & Barbosa, N. (2014). Does venture capital really foster innovation? *Economics Letters, 122*, 129–131.
Fiordelisi, F., Giuseppe, G., & Viktoriia, P. (2024). *Climate change fears: Natural disasters and investor behaviour" review of corporate finance* (Vol. 4) (in press).
Fulghieri, P., & Sevilir, M. (2009). Organization and financing of innovation, and the choice between corporate and independent venture capital. *Journal of Financial and Quantitative Analysis, 44*, 1291–1321.
Gema, A. M., Leal-Millan, A., & Cepeda-Carrion, G. (2016). The antecedents of green innovation performance: A model of learning and capabilities. *Journal of Business Research, 69*, 4912–4917.
Ghosh, S., & Nanda, R. (2010). Venture capital investment in the clean energy sector. *Harvard Business School Entrepreneurial Management Working Paper*.
Gompers, P., Kovner, A., & Lerner, J. (2009). Specialization and success: Evidence from venture capital. *Journal of Economics and Management Strategy, 18*, 817–844.
Gompers, P., & Lerner, J. (2001). The venture capital revolution. *The Journal of Economic Perspectives, 15*, 145–168.
Goss, A., & Roberts, G. S. (2011). The impact of corporate social responsibility on the cost of bank loans. *Journal of Banking & Finance, 35*, 1794–1810.
Gray, W. B., & Shadbegian, R. J. (2003). Plant vintage, technology, and environmental regulation. *Journal of Environmental Economics and Management, 46*, 384–402.
Griliches, Z. (1992). The search for R&D spillovers. *The Scandinavian Journal of Economics, 94*, 29–47.
Guerini, M., & Quas, A. (2016). Governmental venture capital in Europe: Screening and certification. *Journal of Business Venturing, 31*, 175–195.
Hall, B. H., & Lerner, J. (2010). Chapter 14 - the financing of R&D and innovation. In B. H. HALL, & N. ROSENBERG (Eds.), *Handbook of the economics of innovation*. North-Holland.
Hellmann, T., & Puri, M. (2002). Venture capital and the professionalization of start-up firms: Empirical evidence. *The Journal of Finance, 57*, 169–197.
Horbach, J., Rammer, C., & Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact — the role of regulatory push/pull, technology push and market pull. *Ecological Economics, 78*, 112–122.
Hsu, P. H., Tian, X., & Xu, Y. (2014). Financial development and innovation: Cross-country evidence. *Journal of Financial Economics, 112*, 116–135.

King, A. A., & Lenox, M. J. (2001). Does it really pay to Be green? An empirical study of firm environmental and financial performance: An empirical study of firm environmental and financial performance. *Journal of Industrial Ecology, 5*, 105–116.
Kunapatarawong, R., & MartíNEZ-Ros, E. (2016). Towards green growth: How does green innovation affect employment? *Research Policy, 45*, 1218–1232.
Lanoie, P., Patry, M., & Lajeunesse, R. (2008). Environmental regulation and productivity: Testing the porter hypothesis. *Journal of Productivity Analysis, 30*, 121–128.
Leleux, B. T., & Surlemont, B. (2003). Public versus private venture capital: Seeding or crowding out? A pan-European analysis. *Journal of Business Venturing, 18*, 81–104.
Lerner, J. (2000). The government as venture capitalist: The long-run impact of the SBIR program. *Journal of Private Equity, 3*, 55.
Lerner, J. (2002). When bureaucrats meet entrepreneurs: The design of effective `Public venture capital' programmes. *The Economic Journal, 112*, F73–F84.
Levin, J., & Tadelis, S. (2005). Profit sharing and the role of professional partnerships. *Quarterly Journal of Economics, 120*, 131–171.
Li, J.-J., Xu, C., Fung, H.-G., & Chan, K. C. (2021). Do venture capital firms promote corporate social responsibility? *International Review of Economics & Finance, 71*, 718–732.
Lindsey, L. (2008). Blurring firm boundaries: The role of venture capital in strategic alliances. *The Journal of Finance, 63*, 1137–1168.
Liu, Y., Wang, A., & Wu, Y. (2021). Environmental regulation and green innovation: Evidence from China's new environmental protection law. *Journal of Cleaner Production, 297*, Article 126698.
Mcgrath, R. G., Tsai, M.-H., Venkataraman, S., & Macmillan, I. C. (1996). Innovation, competitive advantage and rent: A model and test. *Management Science, 42*, 389–403.
Porter, M. E., & Van Der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *The Journal of Economic Perspectives, 9*, 97–118.
Rennings, K. (1998). *Towards a theory and policy of eco-innovation-Neoclassical and (Co-) Evolutionary Perspectives*. ZEW Discussion Papers.
Rennings, K. (2000). Redefining innovation — eco-innovation research and the contribution from ecological economics. *Ecological Economics, 32*, 319–332.
Roy, M., & Khastagir, D. (2016). Exploring role of green management in enhancing organizational efficiency in petro-chemical industry in India. *Journal of Cleaner Production, 121*, 109–115.
Sahlman, W. A. (1990). The structure and governance of venture-capital organizations. *Journal of Financial Economics, 27*, 473–521.
Scholtens, B. (2006). Finance as a driver of corporate social responsibility. *Journal of Business Ethics, 68*, 19–33.
Shen, C., Li, S., Wang, X., & Liao, Z. (2020). The effect of environmental policy tools on regional green innovation: Evidence from China. *Journal of Cleaner Production, 254*, Article 120122.
Soleimani Dahaj, A., & Cozzarin, B. P. (2019). Government venture capital and cross-border investment. *Global Finance Journal, 41*, 113–127.
Tseng, M.-L., Wang, R., Chiu, A. S. F., Geng, Y., & Lin, Y. H. (2013). Improving performance of green innovation practices under uncertainty. *Journal of Cleaner Production, 40*, 71–82.
Tu, Y., & Wu, W. (2021). How does green innovation improve enterprises' competitive advantage? The role of organizational learning. *Sustainable Production and Consumption, 26*, 504–516.
Ueda, M. (2004). Banks versus venture capital: Project evaluation, screening, and expropriation. *The Journal of Finance, 59*, 601–621.
Wadhwa, A., Phelps, C., & Kotha, S. (2016). Corporate venture capital portfolios and firm innovation. *Journal of Business Venturing, 31*(1), 95–112.
Wei, Z., Yuguo, J., & Jiaping, W. (2015). Greenization of venture capital and green innovation of Chinese entity industry. *Ecological Indicators, 51*, 31–41.
Xiang, X., Liu, C., & Yang, M. (2022). Who is financing corporate green innovation. *International Review of Economics & Finance, 78*, 321–337.
Xie, X., Huo, J., & Zou, H. (2019a). Green process innovation, green product innovation, and corporate financial performance: A content analysis method. *Journal of Business Research, 101*, 697–706.
Xie, R.-H., Yuan, Y.-J., & Huang, J.-J. (2017). Different types of environmental regulations and heterogeneous influence on "green" productivity: Evidence from China. *Ecological Economics, 132*, 104–112.
Xie, X., Zhu, Q., & Wang, R. (2019b). Turning green subsidies into sustainability: How green process innovation improves firms' green image. *Business Strategy and the Environment, 28*, 1416–1433.
Xing, C., Zhang, Y., & Tripe, D. (2021). Green credit policy and corporate access to bank loans in China: The role of environmental disclosure and green innovation. *International Review of Financial Analysis, 77*, Article 101838.
Yi, Y., Wei, Z., & Fu, C. (2021). An optimal combination of emissions tax and green innovation subsidies for polluting oligopolies. *Journal of Cleaner Production, 284*, Article 124693.
Zhang, Y., Xing, C., & Wang, Y. (2020). Does green innovation mitigate financing constraints? Evidence from China's private enterprises. *Journal of Cleaner Production, 264*, Article 121698.
Zhang, C., Zhou, B., & Tian, X. (2022). Political connections and green innovation: The role of a corporate entrepreneurship strategy in state-owned enterprises. *Journal of Business Research, 146*, 375–384.