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Article

How Do Sustainability Stakeholders Seize Climate Risk Premia in the Private Cleantech Sector?

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Abstract: This paper explores the strategies and practices of capturing climate risk premia for venture capital (VC) fund managers and entrepreneurs in the private cleantech sector. It also examines the impact of the feed-in tariffs (FITs) policy on the management of cleantech investments. It is shown that a longer investment period, less investment capital in cleantech investment management strategies, and optimistic climate risk management practices will help investors to better capture climate risk premia. In fact, the FITs policy will give rise to VC fund managers and entrepreneurs having a positive view regarding the prospects of the cleantech sector, motivating them to make long-term investments. Furthermore, it is shown that the greater the impact of the FITs policy, the greater the climate risk premia to be captured. In addition, the captured climate risk premia are greater in weaker economic conditions and in times of increased uncertainty with regard to product demand.

Keywords: cleantech innovation; climate risk; feed-in tariffs policy; venture capital investment performance

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1. Introduction

Climate risk is the non-business risk caused by climate change, and government environmental policies are used to hedge it (Schlenker and Taylor 2021; Stroebel and Wurgler 2021; Sautner et al. 2022). Compared with the non-cleantech sector, the cleantech sector faces greater climate risk due to the public good nature of cleantech products. However, the climate risk premia of the cleantech sector are under-exploited because of the lack of investment experience among cleantech investors and entrepreneurs, as well as limited knowledge regarding the cleantech sector. In the literature, there exist many papers on capturing climate risk premia in the public sector (Schlenker and Taylor 2021; Stroebel and Wurgler 2021; Painter 2020), but there are few papers on capturing climate risk premia in the private sector. In fact, there is huge return potential in the private cleantech sector due to the invisible and immeasurable nature of the private sector. This study explores two research questions: What are the strategies and practices adopted by venture capital (VC) fund managers and entrepreneurs that will lead to greater climate risk premia? How can they exploit the climate risk premia in the private cleantech sector?

In this paper, it is hypothesized that the VC fund managers of cleantech change from short-term investment management strategies to long-term investment management strategies with less investment capital but more investment rounds, with both VC fund managers and entrepreneurs adopting optimistic climate risk management practices. Cleantech investment management strategies and climate risk management practices help both VC investors and entrepreneurs to better capture climate risk premia. The government policies that cause changes in investment strategies and practices are modeled by the feed-in tariffs (FITs) policy, since it is the most widely used and most effective environmental subsidy policy (Ghosh and Nanda 2010; Bürer and Wüstenhagen 2009; Couture et al. 2010; Criscuolo and Menon 2015). According to government redistribution theory (Keuschnigg and Nielsen

2004), the government has more information about a sector's prospects, and investors infer signals from government policies and make adjustments to capture market risk premia. The modeling of the FITs policy, which stimulates the change in investment strategies and practices, is parallel to that of the environmental subsidy policy, which stimulates the change in clean innovation (Hicks 1932; Drandakis and Phelps 1966; Acemoglu 2002).

This paper contributes to two streams of literature: one focuses on capturing climate risk premia, and the other analyzes global VC cleantech investment performance. This is the first paper to identify the strategies and practices that can better capture climate risk premia in the private cleantech sector. It shows that the long-term cleantech investment management strategies adopted by VC fund managers and the optimistic climate risk management practices adopted by both VC fund managers and entrepreneurs will help to capture more climate risk premia in the private cleantech sector. Moreover, the previous literature has indicated that the FITs policy will increase the investment capital of VC cleantech (Nahata 2008; Cumming and Walz 2010; Nahata et al. 2014); however, no studies have explored how the FITs policy influences the investment performance of VC cleantech. This study demonstrates that a more generous FITs policy leads to a better investment performance by global VC cleantech.

This study constructs the private cleantech sector by collecting VC-backed cleantech start-ups from Thomson Financial Securities Data Company (SDC) VentureXpert, as the database contains a large amount of start-ups- and VC-related information. VC-backed non-cleantech start-ups were also collected from VentureXpert to compare cleantech and non-cleantech start-ups. Non-VC-backed cleantech start-ups were gathered from the S&P Capital IQ platform to compare the VC-backed and non-VC-backed cleantech start-ups. The entire sample of 17,062 start-ups spans 21 countries and includes 1690 VC-backed cleantech start-ups, 1480 non-VC-backed cleantech start-ups, and 13,891 VC-backed non-cleantech start-ups. For samples with both exit type and exit time information, the Cox hazard model is selected. For samples with only exit type information, the logit model and multinomial logit model are selected. The regression results indicate that only VC-backed cleantech investments are motivated by the FITs policy to exploit greater climate risk premia, while the VC-backed non-cleantech investments and non-VC-backed cleantech investments do not capture extra climate risk premia. This indicates that the long-term cleantech investment strategies and optimistic climate risk management practices of VC fund managers play a more important role in exploiting climate risk premia in the private cleantech sector than the climate risk management strategies and practices of entrepreneurs. This paper indicates that ensuring the continuation and smooth financing of cleantech start-ups is key for cleantech investors to exploit climate risk. The findings are robust where country-level macroeconomic factors, VC-specific factors, and industry- and firm-level factors are under control.

The remainder of the paper is organized as follows: Section 2 presents a literature review on climate risk and the impact of the FITs policy on climate-risk-seizing behaviors in the private cleantech sector; Section 3 presents the development of hypotheses on climate risk management practices and cleantech investment strategies; Section 4 describes the research methodology used in this study; Section 5 reports the research findings; Section 6 is the discussion; Section 7 deals with endogenous issues and a robustness check; and Section 8 concludes the paper, as well as discussing the limitations and future research directions.

2. Literature Review

2.1. The High Climate Risk of the Private Cleantech Sector and the Reason for the under-Exploitation of Climate Risk Premia in the Private Cleantech Sector

Cleantech companies are entities that deliver products, services, or processes that are waste-saving (Pernick and Wilder 2007; Cumming et al. 2016; Bjornali and Ellingsen 2014). For instance, Sunrun Inc., San Francisco, CA, a United States-based provider of residential solar electricity, is a cleantech company.

Compared with the non-cleantech sector, the cleantech sector faces greater climate risk and should have a higher return. Unlike non-cleantech products, the demand for which is determined by the price and demand equilibrium, the demand for cleantech products is also affected by climate-risk-related factors.

Environmentalists and the activities of environmental organizations could increase the climate risk that a cleantech faces through affecting the direction of clean technology development. For instance, protesting against the usage of tidal clean energy generation technology because of the damage it causes to marine habitant environments and marine life prevents its widespread usage. The change in the price of the natural resources used to generate cleantech products also increases the degree of climate risk that the cleantech sector faces by affecting the market demand for clean products. The dramatic fall in the price of polysilicon by 89% between 2009 and mid-2011 caused Solyndra's core solar panel generating technology, a clean energy generation technology CIGS, to lose its low-priced competitive advantage in the market, resulting in the firm filing for bankruptcy. For a detailed comparison of cleantech and non-cleantech start-ups, refer to Appendix B.

However, in reality, investment in the private cleantech sector underperforms. From a product marketing perspective, low demand for cleantech products is one reason (van den Heuvel and Popp 2022). Limited chances for cleantech start-ups to be acquired by established companies (Ghosh and Nanda 2010) along with the intense capital and long investment period needed for cleantech start-ups to succeed are other major reasons for the underperformance of private cleantech investments. As mentioned above, Solyndra, a manufacturer of photovoltaic systems, raised USD 970 million in equity for a planned initial public offering (IPO) in 2010; however, they revoked the IPO and filed for bankruptcy in 2011 due to the large capital gap between the firm's operational needs and the capital amount it financed. The failure of Solyndra shows that the mismatching of the operational capital needs of cleantech start-ups and capital financing is detrimental to the development of cleantech start-ups. In fact, many cleantech start-ups have failed, as they were unable to raise sufficient follow-on funding to fill the massive funding gap during production and commercialization, a "valley of death" stage, over the ten, or even more, years in their development path.

In this study, entrepreneurs and VC fund managers are selected as the research focus, since they are the major players in the private cleantech sector. VC fund managers and entrepreneurs are adept at seizing risk premia in the imperfect markets caused by a product's public good nature (Dean and McMullen 2007; Cohen and Winn 2007; Hart and Christensen 2002). VC investments in the cleantech sector experienced a surge of approximately 47% from USD 1 billion to USD 5 billion during the first boom from 2004 to 2008, followed by a second boom from 2008 to 2011. However, there was a large investment withdrawal from 2012 due to unexpected investment performance. The third boom has been taking place since 2016. In 2018, VC and private equity (PE) investment in the cleantech sector jumped by 127% to USD 9.2 billion. The major reasons why VC fund managers have failed to capture climate risk premia in the private cleantech sector are their unwillingness to change to the business model that best fits the cleantech start-up's development (Bocken 2015; Deme 2018) and their lack of operational experience regarding cleantech start-ups (Gaddy et al. 2017). The major reason why entrepreneurs have failed to capture climate risk premia is their lack of operational experience regarding cleantech start-ups.

2.2. FITs Policy's Effect on Entrepreneurs and VC Fund Managers' Thoughts and Behaviors

The FITs policy is a subsidy policy aimed at increasing the production of, and demand for, clean electricity by reimbursing the clean electricity generator and clean electricity users. Governments and government-designated electricity suppliers sign a 10-to-25-year contract with qualified electricity producers and consumers to make payments to them according to the payment schedule specified in the contract. The FITs payment rate is mainly a fixed rate determined by the cost of building the clean-electricity-generating plant, and the unit of payment is per kilowatt hour (kWh).

Governments use the FITs policy to transfer capital from the non-cleantech sector to the cleantech sector to lower the generation cost of cleantech products, increase the demand for cleantech products, stimulate clean technology development (Acemoglu 2002; Acemoglu et al. 2014; Acemoglu et al. 2016), and make the products of cleantech start-ups competitive (Butler and Neuhoff 2008; Lipp 2007). The FITs policy is stable, continuous, and credible (Criscuolo and Menon 2015), making it the ideal complementary source of funding for VC funding for the development of cleantech start-ups during "the valley of death" stage. The FITs policy also incentivizes acquirers to obtain cleantech start-ups (Ghosh and Nanda 2010). In short, the FITs policy signals the prospect of the cleantech sector to VC fund managers and entrepreneurs. However, it is not clear how the FITs policy affects the cleantech investment behaviors of VC fund managers and entrepreneurs. This paper fills the gap by proposing corresponding hypotheses and empirically testing them.

3. Private Cleantech Sector Climate Risk Premia Seizing Behavior Hypothesis Development

To capture climate risk in the private cleantech sector, VC fund managers and entrepreneurs need to tailor cleantech investment management strategies according to the features of cleantech start-ups and adopt optimistic climate risk management practices. The FITs policy can stimulate VC fund managers to change from traditional short-term, fast-growth, large-return investment management strategies to long-term, low-capital-investment cleantech investment management strategies with greater investment rounds. The FITs policy can also encourage entrepreneurs and VC fund managers to conduct optimistic climate risk management practices.

According to the redistribution policy theory, governments have superior knowledge on the current and future prospects of all investment sectors due to their comprehensive countrywide investigations and analysis (Keuschnigg and Nielsen 2004). Governments can use the FITs policy to redistribute capital to the promising cleantech sector to accelerate its development. VC fund managers can then form a positive perception on the cleantech sector. These positive perceptions encourage them to adopt long-term investment management strategies when monitoring cleantech start-ups and managing cleantech investments. VC fund managers evaluate the performance of cleantech investments and periodically determine whether to provide the next round of funding. Stimulated by the FITs policy, they will loosen the return requirements for the start-ups to be eligible for the next round of funding, and become comfortable with long-term investment periods when managing cleantech investments. These long-term investment strategies adopted by VC fund managers will empower cleantech start-ups to be more resilient when faced with climate risk. The cleantech start-ups will have more time and financial support to commercialize their technology as new products and services if there is a sudden change in the price of the raw materials used to create their cleantech products.

Hypothesis 1. *The FITs policy motivates VC fund managers to adopt cleantech investment management strategies with long-term investment periods, less investment capital per round, and more investment rounds. These strategies will help VC fund managers to better capture climate risk premia in the private cleantech sector. The FITs rate is expected to be positively associated with the investment performance of VC cleantech.*

The FITs policy also motivates VC fund managers and entrepreneurs to conduct optimistic climate risk management practices. For instance, many small businesses suffered from high maintenance costs and low-revenue dilemmas during the COVID-19 pandemic. Entrepreneurs could adopt the optimistic climate risk management practice of switching to remote work schedules and adjusting salary structures to reduce operational costs for the firm to survive. By doing so, they have the option to return to pre-COVID-19 normal operations at a low cost, with the option to lay off workers to further lower operational costs. Firms could also adopt the pessimistic strategy of laying off some employees permanently. However, compared with the optimistic strategy, the cost for firms who adopt the pessimistic strategy to rehire employees to restore pre-COVID-19 normal operations is high. For firms with less options, they have to lay off more employees when the situation worsens. Even though both strategies can reduce operational costs in financial statements, optimistic climate risk management practices are more valuable for the long-term development of firms, and the return-back option helps firms to be more resilient when capturing climate risk premia.

Hypothesis 2. *The FITs policy motivates VC fund managers and entrepreneurs to adopt optimistic climate risk management practices to capture more climate risk premia in the private cleantech sector, and the FITs rate is expected to be positively associated with the cleantech investment performance of VC and entrepreneurs.*

4. Methodology

4.1. Sample Construction and Summary Statistics

This study constructs a private sector sample from two data platforms: Thomson Financial Securities Data Company (SDC) VentureXpert and the S&P Capital IQ platform. VC-involved cleantech and non-cleantech investment information was collected from the SDC VentureXpert (VentureXpert), and non-VC-involved cleantech investment information was gathered from the S&P Capital IQ platform. For the VC-involved cleantech and non-cleantech investment information, the study follows Nahata et al. (2014) to filter out all the start-ups who received initial investment from the lead VC[1] from 2000 to 2011. There are 15,581 VC investments from 21 countries. The cleantech investments were identified by matching keywords from the Cleantech Group categories (see Appendix A) with the firms' business descriptions and product descriptions from SDC VentureXpert (see Cumming et al. 2016 for a detailed description of methodology). There are 1690 VC cleantech investments and 13,981 VC non-cleantech investments. For the non-VC-involved cleantech investments, the Independent Power and Renewable Electricity Producers industry subcategory under the Utilities category from the S&P Capital IQ platform was followed. Start-ups founded prior to 2012 and without VC/PE ownership within the latest 61 quarters were classified as non-VC-involved cleantech investments. There was a total of 1480 non-VC-involved cleantech investments.

Figure 1 describes the sample construction process. The whole sample includes 17,062 start-ups in 21 countries. It is divided into four sub-samples, namely 1159 VC cleantech investments in developed economies (6.79%), 541 VC cleantech investments in emerging economies (3.11%), 13,893 VC non-cleantech investments in developed economies (81.42%), and 1480 non-VC-involved cleantech investments in developed economies (8.67%). Investments in developed economies account for 96.89% of the whole sample, VC-involved investments make up 91.33%, cleantech investments form 18.57%, and VC cleantech investments constitute 12.17%.

As can be seen from Table 1A,B, the success rate of the VC-backed cleantech start-ups (18.55%) is more than two times greater than that of the non-VC-backed cleantech start-ups (8.31%), which is consistent with the VC value-adding effect (Sørensen 2007). However, the success rate of the VC-backed cleantech start-ups (18.55%) is slightly lower than that of the VC-backed non-cleantech start-ups (19.31%), which indicates the underperformance of VC cleantech investments. The global sample is relatively evenly distributed across all countries, with investments in the United Kingdom accounting for approximately 20% of the entire sample. This assumes that the results are not affected by a single country.

Interesting findings can be drawn from the comparison between developed and emerging economies. First, the success rate of VC-backed cleantech start-ups in emerging economies (26.74%) is higher than that of VC-backed cleantech start-ups in developed economies (18.55%). This indicates that there are more climate risk premia in emerging economies, which have high volatility, immature legal environments, and a complicated social and economic environment. Second, the success rate of VC-backed cleantech start-ups in China is quite high at 33.21%, indicating that cleantech investment in China is worth further investigation.

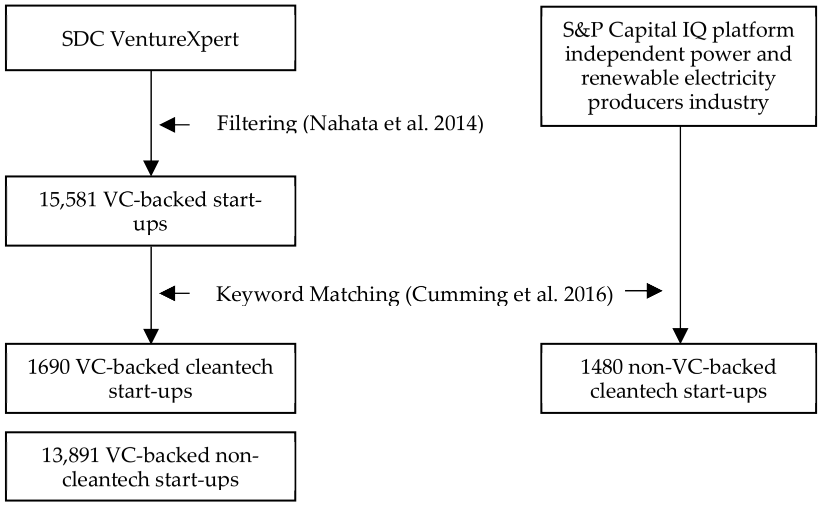


Figure 1. Sample construction process (Nahata et al. 2014; Cumming et al. 2016).

Table 1. Sample distribution (SDC VentureXpert; S&P Capital IQ).

(A) Developed Economies.

	Renewable Sector				**Traditional Sector**	
	VC-Backed Cleantech		**Non-VC-Backed Cleantech**		**VC-Backed Non-Cleantech**	
Country	**Successful**	**Unsuccessful**	**Successful**	**Unsuccessful**	**Successful**	**Unsuccessful**
Australia	58	23	6	84	205	545
Austria	18	0	0	0	31	181
Belgium	23	4	1	27	35	282
Denmark	32	3	1	25	65	318
Finland	38	3	1	22	78	546
France	129	23	3	194	364	2135
Germany	91	32	2	113	359	1314
Israel	32	4	4	14	69	247
Italy	90	11	13	146	66	247
Japan	26	7	7	56	131	532
Netherlands	82	11	2	31	98	545
Norway	37	0	3	54	49	260
Portugal	17	0	2	17	21	183
Spain	64	21	63	163	113	579
Sweden	42	9	2	39	166	673
Switzerland	14	3	1	41	74	187
UK	151	61	12	331	758	2250
Total	215	944	123	1357	2682	11,210
Percentage	18.55%	81.45%	8.31%	91.69%	19.31%	80.69%

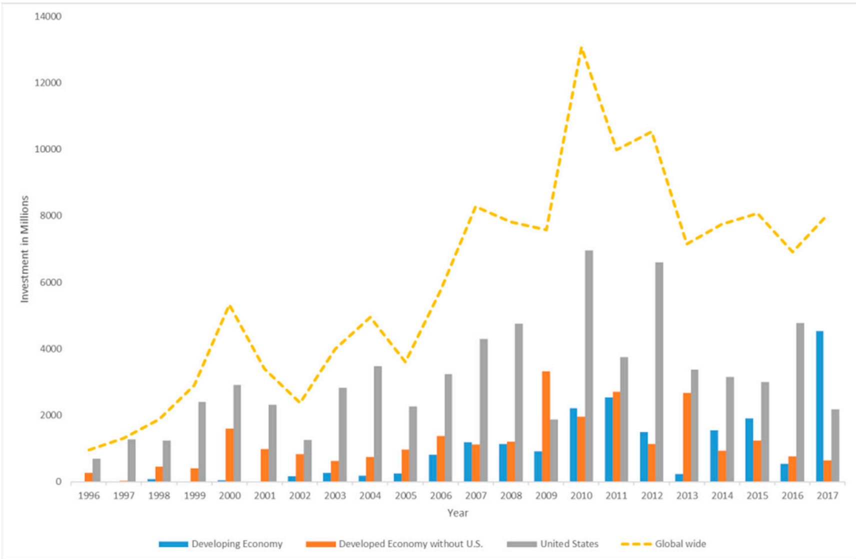
(B) Emerging Economies.

	Renewable Sector	
	VC-Backed Cleantech	
Country	**Successful**	**Unsuccessful**
China	93	187
India	24	109
South Korea	22	85
South Africa	3	8
Total	142	389
Percentage	26.74%	73.26%

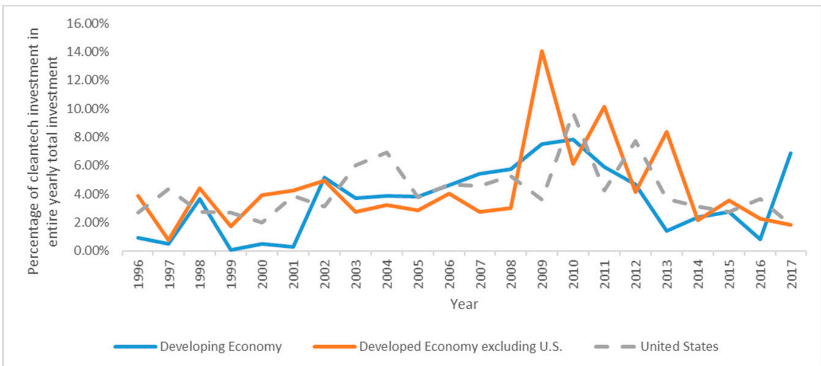
In terms of the investment performance of VC cleantech and non-cleantech start-ups, 2006 was the turning point. Before 2006, the success rate of cleantech start-ups was higher than that of non-cleantech start-ups. After 2006, the success rate of non-cleantech start-ups was higher than that of cleantech start-ups. The reason for this is that the pre-2006 higher success rate of cleantech start-ups was driven by the small number of cleantech start-ups and more VC investment in the cleantech sector. However, after the first boom of 2006, the success rate became diluted.

As can be seen from Figure 2A,B, the ratio of VC cleantech investment capital in developed economies over the total VC investment capital surges from 3% in 2008 to 14%

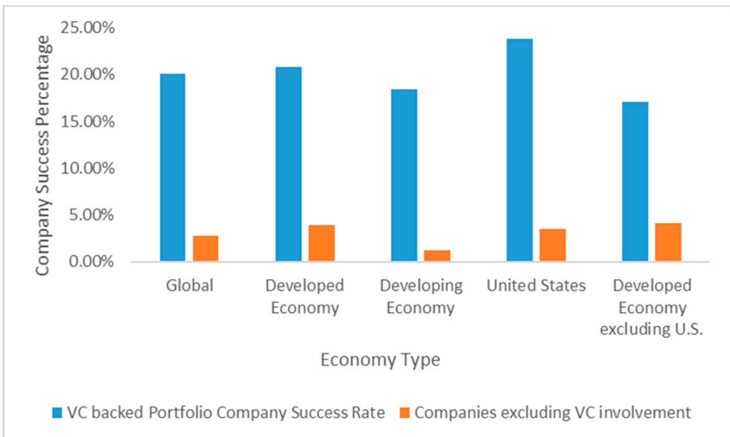
in 2009. Furthermore, the ratio of VC cleantech investment capital in emerging economies over the total VC investment capital increases from 1% in 2016 to 8% in 2017. Developed economies drove the first and second boom in cleantech investments, while emerging economies are driving the third boom in VC cleantech investments, which started in 2016. The United States was the center for global VC cleantech investments, while emerging economies are becoming the new focus for these investments.



(**A**) Global VC cleantech investments.



(**B**) Ratio of VC cleantech investments over total VC investments.



(**C**) Success rate of global VC-backed cleantech start-ups.

Figure 2. Global venture capital (VC) cleantech investments.

As can be seen from Figure 2C, VC plays a very important role in helping cleantech start-ups to succeed. The lower-than-average success rate of cleantech start-ups and the above-average growth rate in cleantech investment capital in emerging economies indicate huge opportunities for capturing climate risk premia in emerging economies.

4.2. Model Construction and Variable Construction

Following the literature, the Cox proportional hazards regression model is selected as the main regression model, and the model specifications are listed below. The left-hand-side variable is the hazard ratio calculated from the partial likelihood of a successful VC cleantech investment, and the right-hand-side variables are the risk factors.

Following the norm in the VC literature, VC firm-related and start-up-related risk factor variables include the lead VC firm age, lead VC reputation, VC syndication size, lead VC yearly cleantech investment capital[2], dummy variables indicating whether VC syndication includes both local and U.S. VC firms and whether a U.S. VC firm exists in the VC syndication, and the business stage of the cleantech start-ups (seed, early, expansion, or late stage) at the time of the lead VC's initial investment. Country-level risk factors include cultural differences between the home country of the cleantech start-ups and the VC firms (Nahata et al. 2014; Cumming et al. 2016), the legal environment indicator of the home country of the cleantech start-ups (Nahata et al. 2014), stock market development degree (Nahata et al. 2014), GDP per capita (Nahata et al. 2014), openness to trade (Nahata et al. 2014), oil price (Cumming et al. 2016; Aghion et al. 2016), environmental carbon tax policy[3] (Popp 2002; Acemoglu et al. 2016; Aghion et al. 2016), resource-depletion degree[4] (Acemoglu et al. 2012), clean technology innovation degree (Popp 2002; Acemoglu et al. 2012), and the capability of the cleantech start-ups to capture the political risk premia (Dean and McMullen 2007; Cohen and Winn 2007). The yearly risk factor includes yearly global VC cleantech investment capital (Cumming et al. 2016).

$$\begin{gathered}\text{Ln (h (VC success investment}_{ijk})/\ h_0\ \text{(VC success investment}_{ijk}) = \text{EXP } (b_1 * \text{FITs\_rate}_{jk} + \\ b_2 * \text{Category\_company\_development\_stage}_{ijk} + b_3 * \text{Category\_VC\_syndication\_U.S.\_local}_{ijk} + \\ b_4 * \text{Category\_U.S.\_VC}_{ijk} + b_5 * \text{Lead\_VC\_age}_{ijk} + b_6 * \ln\text{ (VC\_syndication\_size}_{ijk}) + \\ b_7 * \text{Lead\_VC\_cleantech\_investment}_{ijk} + b_8 * \text{Global\_VC\_cleantech\_investment}_j + \\ b_9 * \text{Hofstede\_culture\_distance}_k + b_{10} * \text{Legal\_index}_k + b_{11} * \text{Stock\_market\_performance}_{jk} + \\ b_{12} * \text{Diff\_ln (GDP\_per\_capita)}_{jk} + b_{13} * \text{Country\_openness}_{jk} + \text{Year\_fixed\_effect} + \text{Country\_fixed\_effect} + \\ \text{Industry\_fixed\_effect})\end{gathered}$$

Here, i refers to individual start-ups; j denotes the year when start-up i received the initial VC investment; and k represents the country of the start-up i. Observation ijk stands for the individual start-up i in country k who received the initial VC investment in year j.

For the non-VC-backed cleantech start-ups, since only the performance category variable information is available, the logit model and the multinomial logit model are selected to estimate the probability of successful investments.

The values of the right-hand-side variables are selected at the year when the start-up received the initial lead VC investment, and are thus earlier than those of the left-hand-side variables. Reverse causality (e.g., increased VC investments may cause a generous FITs rate) is unlikely. As the study uses the past right-hand-side variables to predict the future left-hand-side variables, the model is free of look-ahead bias (see Nahata et al. 2014 for a similar construction). The alternative explanation (i.e., the spillover effect of foreign FITs policies) is also unlikely, since the marginal effect of domestic policies on innovation can be 25 times stronger than that of foreign policies (Dechezleprêtre and Glachant 2014).

The VC cleantech investment performance is measured by the likelihood of a successful VC cleantech investment. A successful VC cleantech investment is defined as an investment in which the VC cultivates the cleantech start-up to the development stage of going public or being acquired. In accordance with the VC literature (see, e.g., Cumming et al. 2017; Nahata 2008; Nahata et al. 2014), the study measures the VC investment performance by calculating the partial likelihood of a successful VC cleantech investment. The greater the value of the partial likelihood, the better the VC investment performance, and the better the capture of climate risk premia. The variables used to calculate the partial likelihood include a VC investment performance category variable, which equals 1 if the VC cultivates the start-up to an IPO or being acquired, and 0 otherwise; and a VC investment duration variable, which is equal to the time that VC spent on cultivating the start-up to success. The investment duration is calculated by taking the logarithm of the time interval between the lead VC initial investment in the start-up and the lead VC exiting the company in quarter units. In the study, the time point to observe VC investment performance is set as the beginning of 2017.

Following the norm in the literature, the FITs policy is measured by the FITs rate variable. The study uses the OECD Environment Directorate (OECD ENV) dataset to collect the FITs rate information. The dataset provides countrywide FITs information in 36 OECD and non-OECD countries over seven cleantech sectors from 2000 to 2017. The dataset has also been cross-checked with other FIT databases (e.g., the REN21, IEA/IRENA, and OECD PINE databases). The FITs rate is provided at the country/year level, and is converted into USD with the kWh unit. The study measures the FITs policy by normalizing the FITs rate over seven sectors at the country/year level (for a similar application of such measurements, see Dijkgraaf et al. 2014; Criscuolo and Menon 2015). The construction processes and sources of other variables are documented in Table 2.

Table 2. Variable measurements and sources.

(A) FITs Rate and VC Investment Performance Variables.		
Variables	**Measurement**	**Source**
VC investment performance	Logarithm of time interval between the time start-ups received initial lead VC investment to the time lead VC withdrew from the start-ups in quarters observed at the beginning of 2017	VentureXpert
FITs rate	The sum of FITs rate in seven sectors divided by seven	OECD ENV
(B) VC Specific Variables.		
Variables	**Measurement**	**Source**
VC syndication size	Number of VC firms in a VC syndication	VentureXpert
Lead VC age	Number of years from lead VC's initial establishment to the year lead VC makes initial investment to the cleantech start-up	VentureXpert
Lead VC reputation	Cumulative number of firms VC firm invested, number of success investment VC made, number of IPOs VC involved in, and number of investment rounds VC firm made since the year 1996 until the year lead VC makes initial investment to the cleantech start-up	VentureXpert
VC yearly cleantech investment	Yearly overall global VC investment in sustainable sector	VentureXpert
Lead VC firm's cleantech investment	Lead VC firm's accumulated cleantech investment by the time lead VC first invests in the cleantech start-up	VentureXpert
U.S. and local VC firms in VC syndication	Equals one if both U.S. VC and local VC firms are present in the VC syndication	VentureXpert
U.S. VC firm in VC syndication	Equals one if U.S. VC firm is present in the VC syndication	VentureXpert

Table 2. *Cont.*

(C) Major Institutional Variables.		
Variables	**Measurement**	**Source**
Hofstede culture distance	Hofstede culture distance between portfolio company	Taras et al. (2022)
Legal environment	Normalized sum of country-specific shareholder rights, enforcement rights, and accounting standards	LaPorta et al. (1997, 1998)
Stock market development	Cumulative number of IPOs in a country since 1993 until the year the cleantech start-up received initial investment from lead VC	SDC New Issues Database and World Bank
(D) Additional Country-level Variables.		
Variables	**Measurement**	**Source**
GDP per capita	First difference in the logarithm of country's GDP divided by the country's population	World Bank
Country openness to trade	First difference in the ratio of country's exports plus imports divided by the country's GDP	World Bank
FITs policy's enforcement stringency degree	Country's Environmental Policy Stringency (EPS) index	OECD ENV
Environmental carbon tax policy	Country's environmentally related tax divided by country's GDP	OECD ENV
Resource depletion degree	Extraction degree of material resources	OECD ENV
Start-ups' capability to capture cleantech premia	Global cleantech innovation index	The Cleantech Group
Clean technology innovation degree	Country's triadic patent count, country's triadic patent count divided by total yearly triadic patent count, country's USPTO patent application count, country's USPTO application count divided by total yearly USPTO application count	OECD ENV
Cleantech product demand uncertainty	Standard deviation of monthly WTI spot price per year	St. Louis Fed
(E) Additional Category Variables.		
Variables	**Measurement**	**Source**
Cleantech sector identification variable	Equals one if start-ups are identified as cleantech start-ups	VentureXpert
Pre-commercialization identification variable	Equals one if start-ups received the initial lead VC investment at seed, early stages	VentureXpert
VC involvement identification variable	Equals one if start-ups are backed by VC	VentureXpert

5. Results

Table 3 shows the main estimation results. Panel A of Table 3 is the Cox hazard regression for the 1159 VC cleantech investment samples. Panel B is the logit regressions for the 2639 investment samples, where VC cleantech comprises 44% of the sample and non-VC-involved cleantech amounts to 56%. Panel C is the Cox hazard regression for the 16,236 investment samples, which includes VC cleantech and VC non-cleantech.

Based on models 1–4 in Panel A of Table 3, the estimated parameters of the FITs policy rate variable are significantly positive, which supports the latter part of Hypothesis 1 that the FITs policy rate is positively associated with the performance of VC cleantech investments. For instance, in model 4, the estimated parameter of FITs is 6.02 and the hazard rate is exp (5.67) = 411.58, which means that a USD 0.1 increase in the FITs rate will increase the probability of a successful VC cleantech investment by 41.158 times. VC expertise factors measured by lead VC firm age, U.S. VC presence in the syndication, and VC cleantech investment capital have insignificant parameter estimations. This indirectly supports the first part of Hypothesis 1 that the climate risk premia are captured by VC fund managers through shifting the VC cleantech investment management strategies from the traditional short-term ones to the long-term cleantech investment management strategies, with low investment capital and more investment rounds[5].

Table 3. Analysis of cleantech start-ups.

(A) Cox Hazard Analysis of 1159 VC-Backed Cleantech Start-ups.				
	Parameter Estimates			
Risk Factors	**Model 1**	**Model 2**	**Model 3**	**Model 4**
FITs rate	6.055 ***	5.833 **	5.833 **	6.020
	(0.005)	(0.023)	(0.023)	(0.021)
Lead VC's cleantech investment		−0.137	−0.137	−0.133
		(0.415)	(0.415)	(0.437)
VC yearly cleantech investment			1.520 **	1.500 *
			(0.044)	(0.054)
VC syndication contains both a U.S. VC firm and a local VC firm				0.737
				(0.123)
VC syndication contains a U.S. VC firm				−0.301
				(0.185)
Ln (VC syndication size)				−0.067
				(0.604)
Lead VC age				0.001
				(0.862)
Hofstede cultural distance	1.076 ***	1.117 ***	1.117 ***	1.228 ***
	(0.004)	(0.002)	(0.002)	(0.001)
Legal environment	3.389 **	3.449 *	3.449 *	3.779 *
	(0.024)	(0.052)	(0.052)	(0.066)
Stock market development	0.002 **	0.002 **	0.002**	0.002*
	(0.012)	(0.050)	(0.050)	(0.055)
First difference in ln (GDP per capita)	−1.676	0.629	0.629	0.689
	(0.459)	(0.833)	(0.833)	(0.822)
First difference in country openness	−0.026	−0.019	−0.019	−0.019
	(0.601)	(0.723)	(0.723)	(0.740)
Company development stage (seed, early, expansion or late)	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
Log likelihood	−1380	−1007	−1007	−1006
Harrell's c	0.714	0.750	0.750	0.751
Success VC exits	215	165	165	165
Entire observations	1159	904	904	904

(B) Logit Analysis of 2639 VC-Backed Cleantech Start-Ups and Non-VC-Backed Cleantech Start-Ups.			
	Parameter Estimates		
Risk Factors	**Model 1**	**Model 2**	**Model 3**
FITs rate	−0.116	−0.117	−0.131
	(0.181)	(0.176)	(0.173)
VC involvement indicator		1.080 ***	0.973 ***
		(0.000)	(0.001)
FITs rate × VC involvement indicator			1.191
			(0.691)
Legal environment	0.090	0.248	0.092
	(0.947)	(0.860)	(0.945)
Stock market development	0.000	0.000	0.000
	(0.346)	(0.249)	(0.284)
First difference in ln (GDP per capita)	−4.350 **	−4.424 **	−4.557 ***
	(0.012)	(0.016)	(0.009)
First difference in country openness	−0.017	−0.014	−0.012
	(0.688)	(0.740)	(0.788)
Year-fixed effects	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes
Log likelihood	−875.7	−858.0	−857.8
Pseudo R-squares	0.131	0.148	0.149
Success VC exits	338	338	338
Entire observations	2621	2621	2621

Table 3. *Cont.*

(C) Cox Hazard Analysis of 15,582 VC-Backed Cleantech and VC-Backed Non-cleantech Start-Ups.				
	Parameter Estimates			
Risk Factors	**Model 1**	**Model 2**	**Model 3**	**Model 4**
FITs rate		−0.006	−0.009	−0.171
		(0.995)	(0.993)	(0.863)
Cleantech sector indicator			0.196 **	0.119
			(0.016)	(0.261)
FITs rate × VC involvement indicator				1.353 *
				(0.053)
VC syndication contains both a U.S. VC firm and a local VC firm	0.148			
	(0.104)			
VC syndication contains a U.S. VC firm	−0.132			
	(0.175)			
Ln (VC syndication size)	0.366 ***			
	(0.000)			
Lead VC age	−0.001			
	(0.283)			
Hofstede cultural distance	0.791 ***	0.778 ***	0.777 ***	0.774 ***
	(0.000)	(0.007)	(0.007)	(0.007)
Legal environment	0.425	0.529	0.590	0.574
	(0.103)	(0.236)	(0.191)	(0.208)
Stock market development	0.001 ***	0.001 ***	0.001 ***	0.001 ***
	(0.003)	(0.003)	(0.003)	(0.003)
Stock market condition	−1.001			
	(0.675)			
First difference in ln (GDP per capita)	−0.029	0.194	0.217	0.239
	(0.887)	(0.682)	(0.644)	(0.609)
First difference in country openness	0.006	0.016 *	0.017 *	0.017 **
	(0.418)	(0.084)	(0.060)	(0.037)
Company development stage (seed, early, expansion or late)	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes
Year-fixed effects		Yes	Yes	Yes
Country-fixed effects		Yes	Yes	Yes
Log likelihood	−29,256	−26,916	−26,912	−26,911
Harrell's c	0.602	0.624	0.625	0.625
Success VC exits	3116	2897	2897	2897
Entire observations	16,236	15,050	15,050	15,050

Note: Variables definitions and constructions are reported in Table 2. ***, **, and * represent significance at 1%, 5%, and 10% levels, respectively. *p*-values in the parentheses are adjusted for country-level clustering, and *p*-values are robust when clustering by year.

Consistent with the VC investment performance literature (see Ghosh and Nanda 2010; Nahata et al. 2014; Black and Gilson 1998; Cumming and Walz 2010; Cumming et al. 2016), the major formal and informal institutional risk factors of the cultural distance between the home country of the lead VC firm and the home country of the start-up, the stock market development condition of the start-up's home country, and the legal environments significantly affect the performance of VC cleantech investment. The development stage of cleantech start-ups also affects the performance of VC cleantech investments. The GDP level of a start-up's home country and the degree of openness to trade insignificantly impact the performance of VC cleantech investments. Global VC yearly investments in cleantech sectors have significantly positive estimation parameters. It could be said that the improved clean innovation in the cleantech sector increases the overall competitiveness of cleantech start-ups.

The c-statistics for the Cox hazard regressions are reported in Panel A and Panel C of Table 3, and in Table 4. For other regressions, this study reports Pseudo R2. The c-statistics increase when more risk factors are added to models 1–4 in Panel A of Table 3, indicating the incremental explanatory power of models.

Table 4. Analysis of cleantech start-ups in emerging and developed economies.

(A) Cox Hazard Analysis of 1690 VC-Backed Cleantech Start-Ups in Emerging and Developed Economies.					
	Parameter Estimates				
	Developed and Emerging Economies				
Risk Factors	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
FITs rate	3.910 **	2.984 *	3.227 **	2.487	1.402
	(0.012)	(0.061)	(0.029)	(0.105)	(0.325)
FITs rate × high cultural distance indicator		4.178 **			4.885 ***
		(0.032)			(0.009)
FITs rate × legal environment indicator			3.670 **		−3.185
			(0.034)		(0.230)
FITs rate × stock market development				6.799 ***	9.984 ***
				(0.000)	(0.000)
Emerging economies indicator	0.660	0.761 *	0.533 **	0.114	0.113
	(0.102)	(0.078)	(0.041)	(0.608)	(0.601)
Hofstede cultural distance	0.629	0.008	0.601	0.556	−0.174
	(0.125)	(0.987)	(0.150)	(0.187)	(0.726)
Legal environment	3.317 ***	3.522 ***	2.827 ***	1.669 ***	1.665 ***
	(0.003)	(0.003)	(0.000)	(0.006)	(0.001)
Stock market development	0.001 ***	0.002 ***	0.001 ***	0.001 ***	0.001 ***
	(0.000)	(0.000)	(0.000)	(0.002)	(0.007)
Company development stage (seed, early, expansion or late)	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes	Yes
Log likelihood	−2463	−2461	−2463	−2461	−2457
Harrell's c	0.711	0.714	0.713	0.718	0.721
Success VC exits	357	357	357	357	357
Entire observations	1690	1690	1690	1690	1690
(B) Cox Hazard Analysis of 1690 VC-Backed Cleantech Start-Ups in Developed Economies.					
	Parameter Estimates				
	Developed Economies				
Risk Factors	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
FITs rate	6.055 **	4.922 **	5.665 **	5.497 **	3.614
	(0.005)	(0.020)	(0.017)	(0.019)	(0.125)
FITs rate × high cultural distance indicator		3.560 *			3.849 *
		(0.085)			(0.064)
FITs rate × legal environment indicator			1.773		−16.682
			(0.352)		(0.174)
FITs rate × stock market development				2.424	21.324
				(0.203)	(0.125)
Hofstede cultural distance	1.076 ***	0.426	1.072 ***	1.072 ***	0.383
	(0.004)	(0.473)	(0.004)	(0.004)	(0.504)
Legal environment	3.389 **	3.492 **	3.237 **	2.917 **	0.818
	(0.024)	(0.019)	(0.015)	(0.018)	(0.681)
Stock market development	0.002 **	0.002 **	0.002 **	0.002 **	0.000
	(0.012)	(0.011)	(0.010)	(0.012)	(0.803)
Company development stage (seed, early, expansion or late)	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes	Yes
Log likelihood	−1380	−1379	−1380	−1380	−1378
Harrell's c	0.739	0.742	0.740	0.740	0.744
Success VC exits	215	215	215	215	215
Entire observations	1159	1159	1159	1159	1159

Note: Variables definitions and constructions are reported in Table 2. ***, **, and * represent significance at 1%, 5%, and 10% levels, respectively. *p*-values in the parentheses are adjusted for country-level clustering, and *p*-values are robust when clustering by year. Results are robust, controlling for VC annual cleantech investment.

Panel B of Table 3 shows the regressions test for Hypotheses 1 and 2. In the mixed sample of VC cleantech investments and non-VC-involved cleantech investments in models 1–3, insignificant negative parameter estimates for the FITs policy rate variable along with the positive estimated parameters of the interaction term of the VC involvement indicator and the FITs policy rate variable indicate that the climate risk premia of the private cleantech sector is mainly captured by the climate risk management behaviors and the cleantech investment behaviors of VC fund managers. The FITs policy rate, which motivates the VC to shift to long-term cleantech investment strategies and the optimistic climate risk management practices, is the major mechanism to capture climate risk premia. The optimistic climate risk management practices of entrepreneurs are less significant in capturing climate risk premia in the private cleantech sector. The significantly positive parameter estimation for the VC presence indication variable is consistent with the literature regarding the VC value-adding effect (see Nahata 2008; Sørensen 2007; Megginson and Weiss 1991).

Panel C of Table 3 shows the Cox hazard regression results on the entire VC investments, including the cleantech and non-cleantech sectors. The significantly positive parameter estimate of the cleantech industry identification variable in model 3 indicates that the cleantech sector has greater climate risk premia than the non-cleantech sector. The significantly positive parameter estimation for the interaction variable of the cleantech industry identification variable and the FITs policy rate variable in model 4 indicates that the FITs policy motivates VC fund managers and entrepreneurs to adopt climate risk management practices and cleantech investment management strategies to better capture climate risk in the cleantech sector. However, VC fund managers and entrepreneurs in the non-cleantech sectors are not motivated by the FITs policy to do so. In Panel C of Table 3, model 1 is a replication of Nahata et al.'s (2014) paper, and consistent findings are derived.

Based on the regressions in Table 3, Hypotheses 1 and 2 are confirmed.

6. Discussion

6.1. Analysis of Moderating Factors for Capturing Climate Risk Premia in the Private Cleantech Sector in Emerging and Developed Economies

Table 4 illustrates the moderating factors of capturing climate risk premia in both developed and emerging economies. The study tests for the moderating effect of three institutional variables of cultural distance between the countries of the investors and the cleantech start-ups, the legal environment in the start-up's country, and the degree of stock market development in the start-up's country by taking the interaction term of the FITs policy rate with each variable.

The parameter estimates for the interaction variable of the FITs policy rate and the high cultural distance indicator variables[6] are significantly positive in the developed economies but insignificantly positive in the emerging economies. This indicates that the greater climate risk premia can be captured for investment pairs, with the greater cultural distance in the developed economies. They might be captured by the legitimacy-related climate risk management activities of VC fund managers in the developed economies.

The parameter estimate for the interaction variable of the FITs policy rate and the stock market development variables is insignificantly positive in the developed economies but significantly positive in the emerging economies. This indicates that greater climate risk premia can be captured in the emerging economies with a low degree of stock market development.

The parameter estimate for the interaction variable of the FITs policy rate and the legal environment variables is insignificant for both the emerging and developed economies. Given the significant differences among governments in the emerging and developed economies, the insignificant parameter estimation indicates that there is more room for governments to use legislation to capture climate risk premia.

From the parameter estimates of the emerging economy identification variable from models 1–5, the emerging economies show greater climate risk premia opportunities compared with the developed economies.

6.2. Analysis of the Source and Features of Climate Risk Premia

This paper recategorizes the sample of 1159 VC cleantech investments in developed economies into an IPO sub-sample and an acquisition sub-sample and repeats the Cox hazard regression for the two sub-samples to analyze the features of captured climate risk premia. The IPO sample and the acquisition sample are formed by denoting investments as successful only if the VC-backed start-ups had an IPO or were acquired, with the rest of the set classified as unsuccessful investments. In Table 5, model 1 is the parameter estimation result for the IPO sample, and models 2–5 are the parameter estimation results for the acquisition sample[7]. The parameter estimate for the FITs policy rate variable is marginally significantly positive in the IPO sub-sample in model 1, and the parameter estimate for the FITs policy rate variable is significantly positive in the acquisition sub-sample in model 2. As being acquired means that cleantech start-ups can receive guidance from the acquirer (Bayar and Chemmanur 2011; Brau et al. 2003), it can be inferred that the captured climate risk premia arise from the increased competitive market power of cleantech products.

Table 5. Cox hazard analysis of the sample of 1159 VC-backed cleantech start-ups in IPO and acquisition.

	Parameter Estimates				
Risk Factors	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
FITs rate	15.099	5.645 ***	5.264 **	2.969	2.627
	(0.150)	(0.006)	(0.030)	(0.136)	(0.271)
Pre-commercialization indicator			−0.577 **		−0.576 **
			(0.022)		(0.022)
FITs rate × pre-commercialization indicator			0.711		0.868
			(0.667)		(0.591)
Cleantech product demand uncertainty				−0.193	−0.198
				(0.173)	(0.158)
FITs rate × cleantech product demand uncertainty				0.188 *	0.180 *
				(0.075)	(0.076)
Hofstede cultural distance	2.009 *	0.881 **	0.815 *	0.851 *	0.789 *
	(0.075)	(0.044)	(0.073)	(0.053)	(0.082)
Legal environment	−5.477	7.667 ***	7.338 ***	8.141 ***	7.745 ***
	(0.311)	(0.000)	(0.000)	(0.000)	(0.000)
Stock market development	0.000	0.003 ***	0.003 ***	0.003 ***	0.003 ***
	(0.921)	(0.000)	(0.010)	(0.000)	(0.000)
First difference in ln (GDP per capita)	3.838	−3.000	−2.805	−3.829	−3.599
	(0.554)	(0.206)	(0.245)	(0.140)	(0.169)
First difference in country openness	0.003	−0.034	−0.029	−0.036	−0.031
	(0.978)	(0.471)	(0.534)	(0.430)	(0.496)
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes	Yes
Log likelihood	−223.1	−1122	−1120	−1121	−1119
Pseudo R-squares	0.141	0.066	0.068	0.066	0.068
Success VC exits	38	177	177	177	177
Entire observations	1159	1159	1159	1159	1159

Note: The same as Table 3.

To explore the source of climate risk premia, this paper creates a pre-commercialization investment dummy variable to categorize the investment sample into investments being funded by VC at the commercialization stages and investments being funded by VC at the pre-commercialization stage. In model 3 and model 5 in Table 5, the parameter estimation for the FITs rate index remains significantly positive, the parameter estimation for the pre-commercialization investment dummy variable is significantly negative, and the parameter estimation for the interaction term of the FITs rate index and the pre-commercialization dummy variable is insignificantly positive. This indicates that the captured climate risk premia are mainly from the commercialization stage.

This paper constructs the interaction term between the FITs rate index and the cleantech product demand uncertainty indicator to further explore the features of climate risk premia. The parameter estimation for the interaction variable is significantly positive in model 4 in Table 5. This indicates that greater climate risk premia are captured in times of greater cleantech product uncertainty.

This paper further explores the source of climate risk premia in Table 6. For the IPO sub-sample, the climate risk premia are from the legitimacy value created, and for the acquisition sub-sample, the climate risk premia are from the increased competitive market power of cleantech products.

Table 6. Cox hazard analysis of 1159 VC-backed cleantech start-ups.

(A) Cox Hazard Analysis of 1159 VC-Backed Cleantech Start-Ups in IPO and Acquisition.

	Parameter Estimates					
	IPO Sample			Acquisition Sample		
Risk Factors	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
FITs rate	12.113	11.944	9.363	4.668 **	4.160 **	3.407 *
	(0.194)	(0.301)	(0.339)	(0.027)	(0.022)	(0.082)
FITs rate × high cultural distance indicator	8.240 *		7.838	2.632		2.549
	(0.076)		(0.100)	(0.195)		(0.219)
FITs rate × high cleantech product demand uncertainty indicator		15.706	15.167		3.617	3.514
		(0.221)	(0.234)		(0.179)	(0.188)
Hofstede cultural distance	0.422	1.960	0.471	0.329	0.804 *	0.338
	(0.828)	(0.111)	(0.817)	(0.623)	(0.073)	(0.612)
Legal environment	−5.363	−4.672	−4.533	7.461 ***	7.887 ***	7.896 ***
	(0.300)	(0.367)	(0.341)	(0.000)	(0.000)	(0.000)
Stock market development	0.000	0.001	0.001	0.003 ***	0.003 ***	0.003 ***
	(0.924)	(0.769)	(0.766)	(0.000)	(0.000)	(0.000)
Cleantech product demand uncertainty		−0.162	−0.120		−0.196	−0.183
		(0.733)	(0.781)		(0.146)	(0.180)
First difference in ln (GDP per capita)	3.448	3.225	2.695	−2.999	−3.322	−3.482
	(0.587)	(0.565)	(0.635)	(0.217)	(0.177)	(0.166)
First difference in country openness	−0.024	0.025	−0.006	−0.031	−0.020	−0.022
	(0.812)	(0.789)	(0.950)	(0.510)	(0.674)	(0.644)
Company development stage (seed, early, expansion or late)	Yes	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−221.6	−222.1	−220.7	−1119	−1119	−1119
Harrell's c	0.146	0.145	0.150	0.068	0.068	0.068
Success VC exits	38	38	38	177	177	177
Entire observations	1159	1159	1159	1159	1159	1159

(B) Cox Hazard Analysis of 1159 VC-Backed Cleantech Start-Ups in Entire Sample.

	Parameter Estimates		
	Entire Sample		
Risk Factors	**Model 1**	**Model 2**	**Model 3**
FITs rate	4.829 ***	4.363 *	2.951
	(0.017)	(0.073)	(0.197)
FITs rate × high cultural distance indicator	3.611 *		4.497 *
	(0.084)		(0.070)
FITs rate × high cleantech product demand uncertainty indicator		4.438 *	5.175 *
		(0.099)	(0.066)
FITs rate × high cultural distance indicator × high cleantech product demand uncertainty indicator			−2.358
			(0.177)
Hofstede cultural distance	0.340	1.003 **	0.312
	(0.588)	(0.012)	(0.627)
Legal environment	3.282 **	3.714 **	3.795 **
	(0.033)	(0.025)	(0.023)
Stock market development	0.002 ***	0.002 ***	0.002 ***
	(0.008)	(0.005)	(0.006)
Cleantech product demand uncertainty		−0.140	−0.119
		(0.211)	(0.281)
First difference in ln (GDP per capita)	−1.771	−2.021	−2.239
	(0.440)	(0.331)	(0.289)
First difference in country openness	−0.025	−0.010	−0.014
	(0.608)	(0.830)	(0.773)
Company development stage (seed, early, expansion or late)	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes
Log likelihood	−1377	−1377	−1375
Harrell's c	0.058	0.057	0.058
Success VC exits	215	215	215
Entire observations	1159	1159	1159

Note: The same as Table 3.

Another feature of climate risk is its counter-cyclical relationship with the economic development cycle. Appendix C shows the parameter estimation results for cleantech start-ups that received initial investment from 2000 to 2008 and from 2000 to 2009. The significantly positive parameter estimations for the FITs rate variable in both samples and the higher FITs rate variable parameter estimation value in the 2000 to 2009 sample in model 2 confirm the counter-cyclical features of climate risk premia.

7. Endogenous Issues and Robustness Check

7.1. Alternative Explanation of VC Reputation

The captured climate risk premia could be credited to the good reputation of VC firms rather than their shift to climate-risk-premia-capturing strategies and practices. In Table 7, the study controls for VC reputation variables by using the baseline regression model in Table 3. The parameter estimate for the FITs rate index remains significantly positive after controlling for four measures of VC reputation variables.

Table 7. Cox hazard analysis of 1159 VC-backed cleantech start-ups controlling for VC reputation.

	Parameter Estimates			
Risk Factors	**Model 1**	**Model 2**	**Model 3**	**Model 4**
FITs rate	5.972 ***	6.248 ***	6.001 ***	6.258 ***
	(0.007)	(0.006)	(0.005)	(0.006)
Normalized cumulative VC investment count	−5.095			
	(0.139)			
Normalized cumulative VC success investment		−0.185 *		
		(0.052)		
Normalized cumulative VC-backed IPOs			2.081	
			(0.657)	
Ln (normalized cumulative VC investment rounds)				−0.381 *
				(0.071)
Hofstede cultural distance	1.016 ***	1.181 ***	1.082 ***	1.186 ***
	(0.008)	(0.005)	(0.004)	(0.005)
Legal environment	3.299 **	3.744 **	3.387 **	3.746 **
	(0.034)	(0.015)	(0.024)	(0.015)
Stock market development	0.002 **	0.002 ***	0.002 **	0.002 ***
	(0.015)	(0.008)	(0.012)	(0.008)
First difference in ln (GDP per capita)	−1.736	−1.982	−1.674	−1.964
	(0.416)	(0.376)	(0.460)	(0.380)
First difference in country openness	−0.029	−0.031	−0.026	−0.031
	(0.528)	(0.518)	(0.598)	(0.521)
Company development stage (seed, early, expansion or late)	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
Log likelihood	−1351	−1351	−1380	−1351
Pseudo R-squares	0.057	0.057	0.055	0.057
Success VC exits	211	211	215	211
Entire observations	1142	1142	1159	1142

Note: The same as Table 3.

7.2. Alternative Explanation of Environmental Awareness

The influence of the FITs policy on VC fund managers and entrepreneurs might be explained by their increasing environmental awareness. The high enforcement stringency level of the FITs policy inspires environmental awareness in VC fund managers and entrepreneurs, which will lead them to proactively seize climate risk premia in the cleantech sector. This study considers this alternative explanation by controlling the Environmental Policy Stringency (EPS) index in the regression in model 1 in Table 8. The EPS variable has an insignificant impact on capturing climate risk premia. Thus, the environmental awareness channel is less likely.

Table 8. Robustness check on 1159 VC-backed cleantech start-ups.

	Parameter Estimates			
Risk Factors	**Model 1**	**Model 2**	**Model 3**	**Model 4**
FITs rate	3.793 *	5.140 **	5.052 **	5.096 **
	(0.054)	(0.024)	(0.024)	(0.018)
FITs policy's enforcement stringency degree	0.082			
	(0.717)			
Environmental carbon tax policy		−0.065		
		(0.932)		
Resource depletion degree			−0.001	
			(0.313)	
Start-ups' capability to capture cleantech premia				2.796 **
				(0.019)
Hofstede cultural distance	1.021 ***	1.046 ***	1.037 ***	1.046 ***
	(0.006)	(0.005)	(0.006)	(0.005)
Legal environment	5.436 ***	5.875 ***	4.263 ***	−0.837
	(0.009)	(0.002)	(0.006)	(0.437)
Stock market development	0.002 **	0.002 ***	0.003 **	0.002 ***
	(0.029)	(0.008)	(0.021)	(0.006)
First difference in ln (GDP per capita)	0.453	−1.266	−1.261	−1.262
	(0.822)	(0.578)	(0.596)	(0.576)
First difference in country openness	−0.034	−0.036	−0.039	−0.036
	(0.528)	(0.470)	(0.434)	(0.469)
Company development stage (seed, early, expansion or late)	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
Log likelihood	−1264	−1297	−1297	−1297
Pseudo R-squares	0.055	0.055	0.055	0.055
Success VC exits	197	201	201	201
Entire observations	1109	1145	1145	1145

Note: The same as Table 3.

7.3. Round-Level Panel Regression

The study conducts round-level panel regression, following the methodology of Nahata et al. (2014). For the successful investment sample, the round-level-dependent variable is denoted as 1 in all rounds. For the rest, the round-level-dependent variable equals 1 if a sequential round is presented, and is 0 otherwise. All other explanatory variables are updated at the funding round level. The parameter estimation of the FITs rate variable is marginally significantly positive under the round-level logit and multinomial logit survival analysis.

7.4. Additional Robustness Test

The findings are robust after controlling for the environmental carbon tax policy, the resource depletion degree, and the capability of cleantech start-ups to capture climate risk premia in models 2–4 in Table 8. The findings are also robust after controlling for the clean innovation degree in models 1–4 in Appendix D.

The findings are robust under logit and multinomial logit regression, clustering standard error by year, with different measures of the FITs rate variable: individual FITs rate under seven sectors, aggregate FITs rate over seven sectors, and weighted FITs rate over seven sectors.

8. Conclusions

This paper investigates which strategies and practices would render greater climate risk premia in the private cleantech sector, finding that the long-term cleantech investment management strategies of VC fund managers along with the optimistic climate risk management practices of VC fund managers and entrepreneurs lead to greater climate risk premia in the private cleantech sector. The paper also finds that the FITs policy encourages the long-term cleantech investment strategies and optimistic climate risk management practices of VC fund managers and entrepreneurs. The greater the FITs policy, the greater the climate risk premia that will be seized. The results hold for a battery of robustness tests and alternative explanations.

This study also examines how the strategies and practices lead to greater climate risk premia. It finds that the captured climate risk premia arise from the increased competitive market power of cleantech products and the legitimacy value during the nurturing of cleantech start-ups by VC fund managers and entrepreneurs. The captured climate risk premia are mainly from the commercialization stage of cleantech start-ups. The captured climate risk premia are counter-cyclical to the economic development stage and are greater in times of greater demand uncertainty for cleantech products.

This research is limited to the available data for the private cleantech investment sector. With the acquisition of more data on private cleantech investment, future research could examine different measures of climate risk premia to add rigor to the analysis. Another limitation is the choice of countries. Although the study covers both emerging and developed economies, it focuses mainly on developed economies. The current findings indicate that emerging economies are a fertile field for exploiting climate risk premia. Future research could focus on the seizing of climate risk premia in the cleantech sector in emerging economies, as interesting results could be found. Another future research direction could be the impact of legal regulations on capturing climate risk premia.

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Appendix A. Cleantech Start-Ups Identification Keywords Adapted from the Cleantech Group

This paper categorizes start-ups that contain the following words in their company business description and in their company product information as cleantech start-ups: "green energy", "cleantech", "recycle", "wind power", "solar power", "biomass", "renewable energy", "hydro-electric", "photovoltaic", "geotherm", "sustainable", "biofuel", "green transport", "environmental footprint", "greywater", "electric motor", "advanced materials", "agriculture", "forestry", "air and environment", "energy efficiency", "energy storage", "fuel cells", "marine power", "nuclear", "recycling and waste", "smart grid", and "transportation". The keywords are from Cleantech Group Website (http://www.cleantech.com/, accessed on 1 October 2022).

Appendix B. Comparison between Cleantech and Non-Cleantech Start-Ups

	Cleantech Start-Ups	**Non-Cleantech Start-Ups**
Capital requirement	Intensive in commercialization stage	Intensive in technology research stage
Payback period	More than 10 years	5 to 7 years
Major risks faced	Policy risk, operation risk, political risk	Technology risk
Relevance policy	Environmental policy, SBIR program	SBIR program
Product feature	Public good nature, market accepter	Market creator
VC exit opportunities	Limited	Clear exit mechanism
Information asymmetry degree	Extremely high	High

Appendix C. Cox Hazard Analysis of the Sample of 904 VC-Backed Cleantech Start-Ups

	Parameter Estimates	
Risk Factors	Model 1	Model 2
FITs rate	4.124 *	4.305 *
	(0.092)	(0.098)
Hofstede cultural distance	1.052 **	0.917 **
	(0.014)	(0.026)
Legal environment	1.885	1.567
	(0.238)	(0.404)
Stock market development	0.000	0.000
	(0.881)	(0.916)
First difference in ln (GDP per capita)	−0.601	−1.843
	(0.790)	(0.421)
First difference in country openness	0.021	−0.007
	(0.638)	(0.866)
Company development stage (seed, early, expansion or late)	Yes	Yes
Industry-fixed effects	Yes	Yes
Year-fixed effects	Yes	Yes
Country-fixed effects	Yes	Yes
Log likelihood	−1016	−1098
Pseudo R-squares	0.049	0.052
Success VC exits	165	175
Entire observations	772	904

Note: The same as Table 3, but no asterisk (***) used.

Appendix D. Cox Hazard Analysis of the Sample of 1153 VC-Backed Cleantech Start-Ups

	Parameter Estimates			
Risk Factors	Model 1	Model 2	Model 3	Model 4
FITs rate	5.038 **	4.921 **	5.037 **	5.057 **
	(0.021)	(0.024)	(0.021)	(0.020)
Triadic green patent count	0.000			
	(0.994)			
Triadic green patent count/ total patent		−6.316 **		
		(0.043)		
USPTO patent application count			0.000	
			(0.893)	
USPTO patent application count / USPTO total patent				2.951
				(0.127)
Hofstede cultural distance	1.044 ***	1.031 ***	1.047 ***	1.065 ***
	(0.005)	(0.006)	(0.005)	(0.004)
Legal environment	6.039 ***	6.773 ***	6.005 ***	−5.946 ***
	(0.001)	(0.000)	(0.001)	(0.001)
Stock market development	0.002 ***	0.003 ***	0.002 ***	0.002 ***
	(0.004)	(0.004)	(0.005)	(0.004)
First difference in ln (GDP per capita)	−1.427	−1.438	−1.454	−1.461
	(0.527)	(0.539)	(0.529)	(0.519)
First difference in country openness	−0.037	−0.038	−0.038	−0.036
	(0.451)	(0.427)	(0.451)	(0.464)
Company development stage (seed, early, expansion or late)	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
Log likelihood	−1297	−1296	−1297	−1297
Pseudo R-squares	0.055	0.057	0.055	0.056
Success VC exits	201	201	201	201
Entire observations	1153	1153	1153	1153

Note: The same as Table 3, but no asterisk (*) used.

Notes

1 The lead VC is the VC that has the largest accumulated investment capital in the start-ups across all rounds of financing (Nahata et al. 2014). In case the VC investment capital data is missing, the oldest VC is set as the lead VC.

2 The FITs policy increases VC cleantech investment capital (Cumming et al. 2016).

3 The FITs policy and the carbon tax policy are complementary policies in reducing greenhouse emission and encouraging clean technology development (Aghion et al. 2016).

4 The resource depletion degree is one major determinant of the design and implementation of the FITs policy.

5 VC expertise factors, such as the VC age and VC investment capital, are documented to increase the performance of VC non-cleantech investments, through value-adding monitoring and due diligence activities (Lerner 1994; Gompers 1996; Sørensen 2007; Hochberg et al. 2007; Nahata 2008).

6 The high cultural distance indicator variable equals 1 if the Hofstede cultural distance between the home country of cleantech start-ups and that of the lead VC firm is in the highest Hofstede cultural distance quantile, and 0 otherwise. For the robustness purpose, the paper tested for various grouping numbers of 4 and 5 quantiles, the parameter estimate for the interaction term remains significantly positive.

7 Parameter estimation results are similar for the full sample regression, and a similar but not significant pattern is returned for the IPO sub-sample. Both full regression results and IPO sub-sample results are available upon request.

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