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Sensing the heat: Climate change vulnerability and foreign direct investment inflows

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ABSTRACT

We investigate whether climate change vulnerability determines foreign direct investment (FDI) inflows. We reason that multinational firms foresee a higher climate change vulnerability of host-country a locational disadvantage while making FDI allocation decisions. Utilizing annual data from 152 countries spanning the period 1996–2019 and employing the panel pooled ordinary least square regressions, we evidence that FDI inflows are lower in countries more vulnerable to climate change. We also observe that FDI inflows are only sensitive to climate-related risks in high- and middle-income countries, but not in low-income countries where the market size is a primary driver of FDI inflows. Moreover, we also find that host countries may weaken the adverse effects of climate change vulnerability on FDI inflows by strengthening the economic, institutional, and social environment.

1. Introduction

The impact of climate on economic outcomes has long been acknowledged and evidenced (Dell et al., 2014). Generally, the extant studies show that natural disasters and gradual global warming significantly affect long-run economic growth (Klomp and Valckx, 2014; Kahn et al., 2021). The less clear are the channels through which climate change affects economic outcomes. In this regard, some recent studies have documented that countries with vulnerable climates pay higher costs on sovereign borrowing (Kling et al., 2018), and firms in countries with vulnerable climate face higher financial constraints, pay higher costs of capital, and prefer long-term funding (Huang et al., 2018; Kling et al., 2021). Extending this debate, we have two objectives in this study. First, we explore whether foreign direct investment (FDI from hereafter) inflows are sensitive to a country's vulnerability to climate risks. Second, we investigate whether a country's readiness to cater to climate risks helps alleviate the adverse consequences of climate vulnerability on FDI inflows.

International risk theory (Buckley et al., 2016; Buckley et al., 2020; Okafor et al., 2022) and the eclectic framework also referred to as the OLI (i.e., Ownership, Location, and Internalization) paradigm of Dunning (1977) are widely used to explain FDI inflows to different countries. The former theory suggests that multinational enterprises (MNEs from hereafter) consider host country risks while making FDI decisions. As such, FDI inflows would be lower to countries with higher political, economic and financial risks. According to this theory, MNEs tend to invest in developing, often high risk, countries based on the belief that they can mitigate the risks. The latter, OLI paradigm, suggests that FDI inflows depend on the locational advantages linked with a foreign country. As such, FDI inflows

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are sensitive to host countries' macroeconomic and institutional environment, including the market size, the extent of market openness, infrastructure availability, labor market conditions, institutional environment and economic policy uncertainty (Cheng and Kwan, 2000; Leahy and Montagna, 2001; Bjorvatn and Eckel, 2006; Alfaro et al., 2008; Julio and Yook, 2016). Building on these theories, we argue host country's climate vulnerability is an important risk factor and locational disadvantage that influences multinational firms' FDI decisions.

Climate-related physical and regulatory risks can cause a decrease in FDI inflows to a country. Physical risks, such as extreme weather events, rising sea levels, and natural disasters, can damage infrastructure, disrupt supply chains, and reduce business productivity, thus making countries and regions less attractive for FDI. Additionally, regulatory risks may arise from governments' efforts to combat climate change through policies and regulations such as carbon taxes, emissions trading schemes, and renewable energy targets. These measures can increase the cost of doing business and reduce profitability, which can ultimately discourage FDI. Our main hypothesis is that FDI inflows would be lower in countries with higher vulnerability to climate risks.

We use the climate vulnerability index developed by the Notre-Dame Global Adaptation Initiative (ND-GAIN) to proxy a country's vulnerability to climate change. Higher values of climate vulnerability index represent that a country is more exposed and sensitive to the negative impact of climate change in terms of potential changes in cereal yields, annual ground water recharge, deaths from diseases, heatwave hazard, flood hazard, urban concentration, quality of transport and trade infrastructure, hydropower generation capacity, sea level rise impacts, electricity access, and disaster preparedness.

To conduct our empirical analysis, we collected annual data from 152 countries spanning the period between 1996 and 2019. Utilizing the panel pooled ordinary least square regressions, we find that countries with higher vulnerability to the adverse effects of climate change tend to attract lower FDI inflows. We observe that these findings stand for several robustness tests including alternative measures of climate vulnerability, alternative estimation method of two-step system GMM panel regressions, and endogeneity tests.

We also investigate whether a country's readiness to cater climate risks helps in alleviating the adverse consequences of climate change on FDI inflows. Using ND-GAIN climate readiness index, which captures a country's economic, governance and social readiness, we observe a higher readiness weakens the adverse effects of climate vulnerability on FDI inflows.

We make multiple contributions to the literature. First, we complement the studies which have explored that climate change vulnerability is having grave economic consequences in terms of financing, asset pricing, investment, and economic output and productivity (Volz et al., 2020; Beirne et al., 2021a; b; Kling et al., 2021; Acharya et al., 2022; Boitan and Marchewka-Bartkowiak, 2022; Cevik and Jalles, 2022; Zhang, 2022). Adding to it, we find that a country's higher vulnerability to climate change adversely affects FDI inflows.

Second, we add to the literature which examines the country-level determinants of FDI inflows (Cheng and Kwan, 2000; Leahy and Montagna, 2001; Bjorvatn and Eckel, 2006; Alfaro et al., 2008; Julio and Yook, 2016; Okafor et al., 2022). This literature largely explores institutional, resources, and policy related country-level factors. We find that climate change vulnerability is another potential risk that drives FDI location decisions.

Third, we add to the literature that examines whether and how FDI decisions are influenced by environmental risks (Escaleras and Register, 2011; Li and Zhang, 2019; Li and Gallagher, 2022). These studies largely explore the effects of physical climate risks, such as natural disasters including floods and hurricanes, on the extent of FDI inflows, including whether foreign owned facilities, as compared to local ones, are more exposed to such risks. Extending this debate, we explore whether FDI destination decisions are driven by host country climate vulnerability.

The rest of the paper is organized as follows. The next section discusses the theoretical framework in the context of existing literature. Section 3 outlines data collection procedures. Fourth section introduces empirical methodology. Fifth section reports empirical results. The final section concludes the study.

2. Theoretical framework and literature review

Our study builds on the two streams of recent literature. First stream are the studies that have investigated the effect of climate change on economies. Second stream explores the country-specific determinants of FDI inflows.

Regarding the first stream, there is an active research agenda on the relevance of climate change risks. Climatic factors can directly affect economic outcomes such as output, investment and productivity (Batten, 2018). Effects of climate change are getting more visible. The recent empirical evidence is supporting that sophisticated debt, equities and real estate markets are pricing the climate change risks. For instance, using data from different geographic regions, some studies show that climate change proxies have a significant positive association with sovereign debt yields (Kling et al., 2018; Volz et al., 2020; Beirne et al., 2021a; b; Boitan and Marchewka-Bartkowiak, 2022; Cevik and Jalles, 2022). Considering the spreads on bank loans, Correa et al. (2022) explore that following a disaster corporate loan spreads spike even for those borrowers who were unaffected during the disaster. Loan spreads increase the highest for weaker borrowers with the most extreme exposure to the disasters.

For stocks, Zhang (2022) and Acharya et al. (2022) find that overall stock markets negatively respond to increased climate risks. Bernstein et al. (2019) and Giglio et al. (2021) show that homes that are exposed to the risks of sea level rise or floods sell for lower prices as compared to the similar properties but without exposure to such risks.

Effects are not linear. For instance, Acharya et al. (2022) show that although higher local exposure of GDP to heat stress is associated with higher spreads on municipal bonds arising mainly from the expected increase in energy expenditures and decrease in labor productivity, however the effect is larger for lower-rated, revenue-only and longer-term bonds. For S&P 500 companies, they observe that, with higher exposure to heat stress, expected returns increase on all stocks whereas yields only increase for sub-investment grade corporate bonds but not for investment grade bonds. The effects are only significant after 2013–2015 and for

heat stress exposure but not for other physical risks. Zhang (2022) suggests that economic variables in less developed countries are less responsive to climate risks than those in developed countries, due to a combination of lower awareness of climate risks and the absence of clear climate-related policies.

Some studies such as Cevik and Jalles (2022) and Beirne et al. (2021a) also show that countries' greater resilience offsets some of these adverse effects of climate change. Abdelzaher et al. (2020) explore that countries that are more innovative, internationally open and have better regulatory quality are less vulnerable to the adverse effects of climate change. Countries' better performance in environment, social and governance indicators is also negatively associated with sovereign default risk and bond spreads (Crifo et al., 2017; Capelle-Blancard et al., 2019).

Regarding the second stream, multinational corporations (MNCs) act cautiously while devising overseas investments strategies because of the additional risks involved in international business dealings. In general, MNCs tend to invest in locations with lower risks and higher returns. According to the OLI framework, FDI inflows would be lower in locations with higher risks (Dunning, 1977). For instance, recent studies have shown country-level institutional or policy risks are negatively associated with FDI inflows (Cheng and Kwan, 2000; Leahy and Montagna, 2001; Bjorvatn and Eckel, 2006; Alfaro et al., 2008; Julio and Yook, 2016; Okafor et al., 2022). Recently, the country-specific risks are getting even more important for international business activity due to trade disputes, conflicts, wars, terrorism, fraught political regimes and corruption (Cavusgil et al., 2020). Overseas risks remain relevant even for experienced and professionally owned MNCs (Buckley et al., 2020). According to the UNCTAD,[1] global FDI inflows in 2018 were 13% lower than in the year 2017.

Building on this framework, a scarce recent literature has starting shedding light on how environmental risks affect FDI inflows. For instance, using data from 94 countries over the period 1984–2004, Escaleras and Register (2011) explore that the number of natural disasters striking a country is negatively associated with the FDI inflows. Li and Zhang (2019) show that FDI inflows are relatively higher in South, as compare to the North, of Qinling Mountains–Huai River line of China due to better air quality which leads to lower health risks and insurance costs. Li and Gallagher (2022) show that across countries the foreign-owned facilities are less exposed to physical climate risks, such as floods, heat and water stress, sea level rise and hurricanes, as compared to local-owned facilities. Likewise, FDI from China, which is a major emerging source of outbound FDI, is more exposed to climate related risks such as floods, water stress, and hurricanes across countries, compared with other foreign facilities. Extending this literature, we examine whether MNCs consider a country's vulnerability to climate change as a risk while making investment decisions.

The concept of vulnerability to climate change has grasped attention since the study of Füssel (2007). A higher vulnerability to climate change may affect overall business environment including occupational health and safety, capital investment, and the extent of business activity including in agriculture and tourism sectors of the economy (Dogru et al., 2019; Lu et al., 2019; Ansah et al., 2021). For instance, the literature survey by Ansah et al. (2021) concludes that climate change is associated with injuries, fatigue, exhaustion, psychological stress, cardiovascular and respiratory issues, chronic illnesses including cancer and kidney diseases and in extreme cases, death to workers. Lu et al. (2019) build a production function including rainfall and temperature with standard variables of labor force and technology and observe that increased rainfall and larger variations in temperature negatively affects economic development. Climate change driven increase in temperatures boost the likelihood of droughts that hurts the agri-businesses. Hong et al. (2019) show that returns of stocks of food companies are lower in countries with higher vulnerability to droughts. Dogru et al. (2019) find that tourism sector is more vulnerable, as compared to the whole economy, to adverse consequences of climate change. Wilbanks and Fernandez (2014) frame how human developed roads and urban infrastructure get exposed to climate change. Framework of Linnenluecke et al. (2011) suggests that climate change may disrupt firm operations through floods, droughts or sea level rises, or disruption to firm's resource base, suppliers or customers. Firms may respond by reallocating their operations from vulnerable locations to more safe locations.

Notwithstanding the above discussion, the adoptability to climate change creates enormous new investment opportunities (Kobayashi-Soloman, 2019). For instance, Chen and Chu (2022) argue that although infrastructure deteriorates due to climate change however the adverse effects can be mitigated by expanding investments in infrastructure projects and low-carbon sectors. The model of Lu et al. (2019) also demonstrates that climate change leads to higher capital investments. Chang et al. (2019) frame the economic effects of climate change with Leontief input-output method and show that industrial output decreases with higher global warming and long-term changes in rainfall. And to prevent these negative effects, the capital investments in industrial sector needs to be increased. Abdelzaher et al. (2020) use a sample of 73 countries over the period 1998–2013 and find that a higher R&D expenditures to GDP ratio, openness to trade, and better regulatory quality reduce a country's vulnerability to climate change. Xu et al. (2022) employ firm level data from 43 countries over the period 2001–2020 and show that both short- and long-run climate risks promote value-enhancing corporate risk-taking behavior.

Based on above discussion, we expect climate change vulnerability is likely to influence FDI inflows. Further, whether the effect is positive, or negative is uncertain. We also explore whether countries' greater preparedness minimizes the adverse effects of climate change on FDI inflows.

3. Data collection

We collected data of FDI inflows and other macroeconomic variables from World Development Indicators database. The data of

[1] For reference please visit:https://unctad.org/data-visualization/global-foreign-direct-investment-flows-over-last-30-years

Table 1
Summary statistics. This table reports summary statistics of main variables.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Log(FDI inflows)	3099	20.747	2.511	10.361	27.322
Climate vulnerability	3099	0.430	0.096	0.241	0.705
Climate preparedness	3099	0.418	0.137	0.118	0.816
GDP growth	3099	3.838	4.119	-36.658	53.382
Inflation	3099	7.178	27.594	-18.109	1058.374
Trade-openness	3099	84.055	49.319	1.219	437.327
Labor force	3099	68.130	10.182	40.630	90.340
Market size	3099	16.082	1.740	11.475	21.065

Table 2
Impact of climate vulnerability on FDI inflows. This table presents the regression results regarding the effect of climate vulnerability on FDI inflows and the moderating role of climate preparedness on this relationship. Dependent variable equals natural log of annual FDI inflows in all models. Climate vulnerability, Climate preparedness and their interaction term, Climate vulnerability × Climate preparedness, are the main variables of interest. All models are estimated with Pooled panel OLS regressions with standard errors clustered at country-level. Standard errors are reported in parentheses. * ** , * * and * indicate significance levels at 1%, 5% and 10% levels, respectively.

Variables	Log (FDI inflows)		
	(1)	(2)	(3)
Climate vulnerability	-11.746 * **	-12.236 * **	-19.791 * **
	(4.476)	(4.321)	(5.311)
Climate preparedness			-10.132 * **
			(3.832)
Climate vulnerability × Climate preparedness			23.339 * **
			(8.371)
GDP growth		0.026 * *	0.025 * *
		(0.011)	(0.011)
Inflation		-0.001 *	-0.001
		(0.001)	(0.001)
Trade-openness		-0.026 *	-0.018
		(0.014)	(0.014)
Labor force		0.004 *	0.004 *
		(0.002)	(0.002)
Market size		1.280 * **	1.081 * *
		(0.482)	(0.480)
Constant	24.099 * **	6.691	12.269
	(2.045)	(7.463)	(7.755)
Country FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	3099	3099	3099
Countries	152	152	152

climate vulnerability and readiness indexes was collected from ND-GAIN. All variables are measured at country-level with annual frequency. After dropping observations with missing values, our final unbalanced panel dataset consists of 3099 annual observations for 152 countries over the period 1996–2019. Table A1 in Appendix A lists the countries included in our sample.

4. Empirical methodology

We specify following panel ordinary least squares regression model to examine the impact of climate vulnerability on FDI inflows.

$$Log(FDI \quad inflows)_{c,t} = \alpha_c + \beta_1(Climate \quad vulnerability_{c,t}) + \sum_{k=1}^{k} \beta_k X_{c,t}^{k} + \sum_{c=1}^{C-1} \epsilon_t C_t + \varepsilon_{c,t}. \tag{1}$$

Here, Log (FDI inflows) represents annual FDI inflows for country c at year t. Log (FDI inflows) equals the natural log of annual foreign direct investment inflows of a country.

Climate vulnerability is proxied with the Climate vulnerability index of ND-GAIN. The Climate Vulnerability index measures the propensity or predisposition of human societies to be negatively impacted by climate hazards. It provides a comprehensive measure of climate vulnerability, taking into account a country's exposure, sensitivity and adaptive capacity to climate hazards in six key life-supporting sectors: food, water, health, ecosystem services, human habitat, and infrastructure. The index comprises 36 factors, with 12 factors allocated to each of the three components - exposure, sensitivity, and adaptive capacity - consisting of two factors for each of the six sectors.

Exposure factors include the climate-induced potential changes in cereal yields, population, annual water runoff, groundwater recharge, mortality rate associated with climate-induced diseases, the length of transmission season of vector-borne diseases,

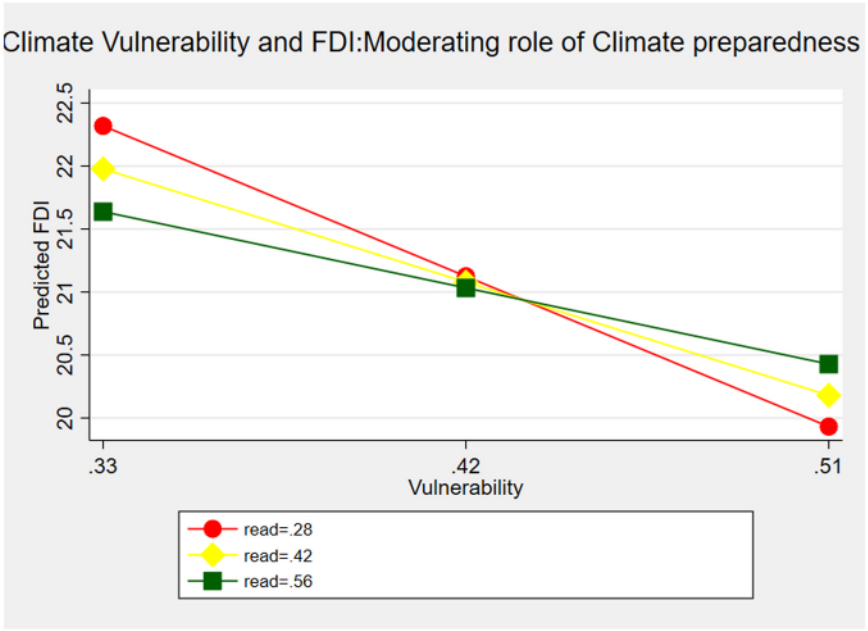

Fig. 1. : Moderating effect of climate readiness on the relationship between climate vulnerability and FDI inflows.

Table 3

Impact of climate vulnerability on FDI inflows- country income levels. This table presents the regression results regarding the effect of climate vulnerability on FDI inflows for various income groups of countries. Dependent variable equals natural log of annual FDI inflows in all models. Climate vulnerability is the main variable of interest. All models are estimated with Pooled panel OLS regressions with standard errors clustered at country-level. Standard errors are reported in parentheses. * ** , * * and * indicate significance levels at 1%, 5% and 10% levels, respectively.

Variables		Log (FDI inflows)	
	(1)	(2)	(3)
	High Income	Middle Income	Lower Income
Climate vulnerability	-26.018 * **	-28.489 * **	-22.854
	(7.001)	(4.888)	(17.085)
GDP growth	0.023	0.022	0.021
	(0.017)	(0.015)	(0.016)
Inflation	0.003	-0.002 * *	-0.002
	(0.020)	(0.001)	(0.002)
Trade-openness	0.010 * **	0.010 * **	0.021 * **
	(0.004)	(0.003)	(0.008)
Labor force	0.051	-0.018	-0.003
	(0.032)	(0.021)	(0.057)
Market size	0.991	3.326 * **	3.915 * **
	(0.685)	(0.494)	(0.702)
Constant	0.000	-16.972 *	-35.299 *
	(0.000)	(9.075)	(19.504)
Country FE	Yes	Yes	Yes
Observations	995	1729	370
Countries	46	85	20

distribution of biomes, marine biodiversity, warm periods, flood hazards, hydropower generation capacity, and sea level rise impacts.

Sensitivity factors include food import dependency, rural population, fresh water withdrawal rate, water dependency ratio, slum population, dependence on external resource for health services, dependency on natural capital, ecological footprint, urban concentration, age dependency ratio, dependency on imported energy, and the population living under 5 m above sea level.

Adaptive capacity factors include agriculture capacity, child malnutrition, access to reliable drinking water, dam capacity, medical staff, access to improved sanitation facilities, protected biomes, engagement in international environment conventions, quality of trade and transport related infrastructure, paved roads, electricity access, and disaster preparedness.

The data of these factors is drawn from a variety of sources, including the World Bank, the United Nations, and national statistical agencies. The vulnerability index ranks countries according to their exposure, sensitivity and capacity to adapt to the negative effects of climate change, the most vulnerable countries receiving a higher score and vice versa. Recent literature has employed climate

Table 4
Impact of previous climate vulnerability on current FDI inflows. This table presents the regression results regarding the effect of climate vulnerability on FDI inflows after including climate vulnerability at various lags. Dependent variable equals natural log of annual FDI inflows in all models. Climate vulnerability is the main variable of interest. All models are estimated with Pooled panel OLS regressions with standard errors clustered at country-level. Standard errors are reported in parentheses. * ** , * * and * indicate significance levels at 1%, 5% and 10% levels, respectively.

Variables	Log (FDI inflows)		
	(1)	(2)	(3)
Climate vulnerability (Lag 1)	-26.941 * **		
	(4.002)		
Climate vulnerability (Lag 2)		-26.635 * **	
		(4.007)	
Climate vulnerability (Lag 3)			-25.313 * **
			(3.857)
GDP growth	0.026 * *	0.029 * **	0.038 * **
	(0.011)	(0.011)	(0.009)
Inflation	-0.001 * *	-0.002 * *	-0.002 * *
	(0.001)	(0.001)	(0.001)
Trade-openness	0.011 * **	0.010 * **	0.010 * **
	(0.002)	(0.002)	(0.003)
Labor force	-0.021	-0.023	-0.020
	(0.016)	(0.017)	(0.018)
Market size	2.900 * **	2.788 * **	2.691 * **
	(0.488)	(0.494)	(0.500)
Constant	-11.148	-9.330	-8.504
	(8.908)	(9.002)	(9.154)
Country FE	Yes	Yes	Yes
Observations	2945	2801	2659
Countries	151	151	151

Table 5
Impact of climate vulnerability on FDI inflows- V20 group of most vulnerable countries. This table presents the regression results regarding the effect of climate vulnerability on FDI inflows using new proxy for climate vulnerability. Dependent variable equals natural log of annual FDI inflows in all models. V20 group of most vulnerable countries is the main variable of interest and equals 1 for sample countries that are the members of V20 group of most climate vulnerable countries, and 0 otherwise. All models are estimated with Pooled panel OLS regressions with standard errors clustered at country-level. Standard errors are reported in parentheses. * ** , * * and * indicate significance levels at 1%, 5% and 10% levels, respectively.

Variables	Log (FDI inflows)
	(1)
V20 group of most vulnerable countries	-4.350 * **
	(0.794)
GDP growth	0.021 * *
	(0.010)
Inflation	-0.003 * *
	(0.001)
Trade Openness	0.014 * **
	(0.002)
Labor Force	-0.007
	(0.019)
Market Size	4.067 * **
	(0.492)
Constant	-41.388 * **
	(7.816)
Country FE	Yes
Observations	3099
Countries	152

vulnerability index to examine the effect of climate vulnerability on economic growth (Adom and Amoani, 2021), inflation (Iliyasu et al., 2023), currency valuation (Cheema-Fox et al., 2022), and corporate sustainable practices (Jia and Li, 2020).

$X^{k}_{c,t}$ represents the country-level control variables including year-on-year GDP growth, inflation, market size (i.e., the natural log of

Table 6
Impact of climate vulnerability on FDI inflows- additional control variables. This table presents the regression results regarding the effect of climate vulnerability on FDI inflows for various after controlling for various governance indicators. Dependent variable equals natural log of annual FDI inflows in all models. Climate vulnerability is the main variable of interest. All models are estimated with Pooled panel OLS regressions with standard errors clustered at country-level. Standard errors are reported in parentheses. * ** , * * and * indicate significance levels at 1%, 5% and 10% levels, respectively.

Variables	Log (FDI inflows)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Climate vulnerability	-27.36 * **	-27.76 * **	-27.19 * **	-26.49 * **	-26.61 * **	-27.36 * **	-22.489 * *
	(4.774)	(4.613)	(4.893)	(4.883)	(4.930)	(4.770)	(10.608)
GDP growth	0.0232 * *	0.0230 * *	0.0236 * *	0.0246 * *	0.0246 * *	0.0232 * *	0.029
	(0.0108)	(0.0107)	(0.0107)	(0.0102)	(0.0107)	(0.0107)	(0.020)
Inflation	-0.00801 *	-0.00741 *	-0.00771 *	-0.00657	-0.00764 *	-0.00788 *	-0.047
	(0.00423)	(0.00427)	(0.00425)	(0.00408)	(0.00420)	(0.00420)	(0.033)
Trade-openness	-0.0266	-0.0242	-0.0258	-0.0264	-0.0276	-0.0255	0.006
	(0.0171)	(0.0173)	(0.0173)	(0.0170)	(0.0170)	(0.0173)	(0.007)
Labor force	0.0108 * **	0.0112 * **	0.0108 * **	0.0109 * **	0.0107 * **	0.0107 * **	0.014
	(0.00242)	(0.00243)	(0.00243)	(0.00237)	(0.00241)	(0.00244)	(0.046)
Market size	2.798 * **	2.828 * **	2.810 * **	2.890 * **	2.815 * **	2.806 * **	2.982 * *
	(0.523)	(0.533)	(0.555)	(0.572)	(0.547)	(0.541)	(1.497)
Voice and Accountability	0.0871						
	(0.180)						
Political stability and absence of Violence/Terrorism		0.170 *					
		(0.0993)					
Government Effectiveness			0.211				
			(0.198)				
Regulatory Quality				0.658 * **			
				(0.193)			
Rule of Law					0.419 * *		
					(0.197)		
Control of corruption						0.186	
						(0.201)	
Economic Policy Uncertainty index							-0.001
							(0.001)
Constant	-8.952	-9.391	-9.193	-10.74	-9.219	-9.007	-20.307
	(9.631)	(9.806)	(10.27)	(10.57)	(10.11)	(9.973)	(26.404)
Observations	2543	2540	2540	2540	2543	2542	366
Countries	140	140	140	140	140	140	20
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

the total population), trade openness (i.e., imports+exports/GDP), and labor force. Similar control variables have been added by Nguyen and Lee (2021) and others. Table A2 in Appendix A reports variables definitions, while Table A3 the expected relationships between FDI inflows and control variables. C_t is a set of country-level fixed-effects dummy variables to control for time-invariant country characteristics such as regulations or cultures. $\varepsilon_{c,t}$ is an error term. We use heteroskedastic-robust standard errors to estimate p-values in regressions.

To examine whether a country's preparedness to cater climate change affects its ability to eliminate or minimize the adverse effects of climate change on FDI inflows, we introduce the following interaction term in the model.

$$Log(FDI\quad inflows)_{c,t} = \alpha_c + \beta_1(Climate\quad vulnerability_{c,t}) + \beta_2(Climate\quad preparedness_{c,t}) + \beta_3(Climate\quad vulnerability_{c,t} \times \text{Climate preparedness}_{c,t}) + \sum_{k=1}^{k}\beta_k X_{c,t}^{k} + \sum_{c=1}^{C-1}\epsilon_i C_t + \varepsilon_{c,t-} \quad (2)$$

Climate preparedness is proxied with the climate readiness index of ND-GAIN. Climate readiness index measures a country's ability to leverage investments and convert them to adaptation actions. It considers the economic, governance and social readiness of countries. Economic readiness is represented by the ease of doing business index. Governance readiness captures political stability, control of corruption, rule of law and regulatory quality. Social readiness incorporates social inequality, ICT infrastructure, education, and innovation. The readiest countries have a higher score and vice versa. The interaction term, $\text{Climate vulnerability}_{c,t} \times \text{Climate preparedness}_{c,t}$, is the main variable of interest and captures the joint effect of climate vulnerability and preparedness. We expect that the adverse effect of climate vulnerability on FDI inflows would be weaker for countries with higher levels of preparedness.

5. Empirical analysis

Table 1 reports summary statistics. Mean value of Log (FDI inflows) is 20.47 with a minimum value of 10.3 and a maximum of 27.3 showing considerable variation in FDI inflows. Climate vulnerability index spans from 0.24 to 0.7 with a mean value of 0.43. There is also considerable variation in countries' preparedness to manage the effects of climate change as shown by the minimum, 0.11, and

Table 7

Impact of climate vulnerability on FDI inflows- dynamic panel two-step system GMM model. This table presents the two-step system GMM regression results regarding the effect of climate vulnerability on FDI inflows. Dependent variable equals natural log of annual FDI inflows in all models. Climate vulnerability is the main independent variable of interest. Model (1) is estimated with Pooled panel OLS regression model. Model (2) is estimated with two-step dynamic system GMM regression results. Model (3) is estimated with panel fixed-effects regression model. P-values are reported in parentheses. * ** , * * and * indicate significance levels at 1%, 5% and 10% levels, respectively.

Variables	Log (FDI inflows)		
	Pooled OLS	Two-step System GMM	Panel Fixed-Effects
	(1)	(2)	(3)
Log (FDI inflows)$_{t-1}$	0.557 * **	0.430 * **	0.345 * **
	(0.000)	(0.000)	(0.000)
Log (FDI inflows)$_{t-2}$	0.259 * **	0.134 * **	0.103 * **
	(0.000)	(0.000)	(0.000)
Climate vulnerability	-2.557 * **	-5.818 * **	-6.825 * **
	(0.000)	(0.000)	(0.001)
GDP growth	0.026 * **	0.020 * **	0.036 * **
	(0.000)	(0.000)	(0.000)
Inflation	-0.000	-0.003 *	0.000
	(0.912)	(0.066)	(0.962)
Trade-openness	0.002 * **	0.003 * **	-0.000
	(0.000)	(0.000)	(0.930)
Labor force	0.004 * *	0.009 * **	-0.014 * *
	(0.012)	(0.000)	(0.041)
Market size	0.150 * **	0.369 * **	0.456 * *
	(0.000)	(0.000)	(0.019)
Time FE	Yes	Yes	Yes
Constant	2.081 * **	5.143 * **	7.604 * *
	(0.000)	(0.000)	(0.019)
Diagnostic tests			
AR(1)		-6.82 * **	
		(0.000)	
AR(2)		-0.35	
		(0.729)	
Hansen test		69.22	
		(0.878)	
F-test		57515.95 * **	
		(0.000)	
No. of instruments		70	
Observations	2628	2628	2628
R-squared	0.896		0.486
Countries	151	151	151

maximum, 0.816, values of climate preparedness index.

Table 2 reports main regression results. Consistent with our expectation, climate vulnerability index enters negative, significant suggesting FDI inflows are lower in countries that are more vulnerable to climate change. Results of control variables, such as higher FDI inflows in countries with higher GDP growth rates, more open to international trade, and with larger market size, are consistent with previous literature. Our findings are in line with previous studies of Li and Zhang (2019) who find negative impact of climate related factors on FDI. These results are also consistent with Escaleras and Register (2011) who conclude that climate risks, such as natural disasters, extreme weather events, and sea-level rise, can significantly reduce FDI inflows to affected countries.

The positive, significant interaction term, Climate vulnerability × Climate preparedness, in Model 3 shows the adverse effect of climate vulnerability on FDI inflows is lower in countries that are more prepared to cater climate change. We also keep the Climate preparedness index in Model 3, where we estimate the joint effect of climate vulnerability and prepareness on FDI inflows. Recent literature (Asongu et al., 2017; Asongu et al., 2018; Asongu and Nwachukwu, 2018a; b) have used the similar regressions to estimate the joint effects with interaction terms.

To demonstrate how climate readiness moderates the relationship between FDI inflows and climate vulnerability, we have plotted Fig. (1) based on the findings from Model 3 of Table 2. The graph depicts the negative association between FDI inflows and climate vulnerability, as evidenced by the downward sloping lines. However, the lines have different slopes at mean and ± one standard deviation of the mean value of the climate readiness index, indicating that the strength of the negative association varies across different levels of climate readiness. In particular, the steeper line, which is marked with circles at both ends, shows that the decline in FDI inflows in response to a one-unit increase in climate vulnerability is more pronounced at lower levels of climate readiness. On the other hand, the flat line, which is marked with squares at both ends, shows that the decline in FDI inflows is less pronounced at higher levels of climate readiness.

Table 8
Impact of climate vulnerability on net FDI inflows. This table presents the regression results regarding the effect of climate vulnerability on net FDI inflows and the moderating role of climate preparedness on this relationship. Dependent variable equals net annual FDI inflows in all models. Climate vulnerability, and the interaction term, Climate vulnerability × Climate preparedness, are the main variables of interest. All models are estimated with Pooled panel OLS regressions with standard errors cluster at country-level. Standard errors are reported in parentheses. * ** , * * and * indicate significance levels at 1%, 5% and 10% levels, respectively.

Variables	Net FDI inflows		
	(1)	(2)	(3)
Climate vulnerability	-43.808 * **	-8.196 *	-8.623
	(4.310)	(4.569)	(5.453)
Climate preparedness			-0.573
			(3.830)
Climate vulnerability × Climate preparedness			1.276
			(8.528)
GDP growth		0.034 * **	0.034 * **
		(0.008)	(0.008)
Inflation		-0.000	-0.000
		(0.000)	(0.001)
Trade-openness		0.003	0.003
		(0.003)	(0.003)
Labor force		-0.028	-0.028
		(0.018)	(0.018)
Market size		1.674 * **	1.660 * **
		(0.505)	(0.523)
Constant	38.751 * **	-0.649	-0.283
	(1.867)	(7.731)	(8.371)
Country FE	Yes	Yes	Yes
Time FE	No	Yes	Yes
Observations	2169	2169	2169
R-squared	0.190	0.387	0.387
Countries	133	133	133

5.1. *Country income levels and the effect of climate change on FDI inflows*

Zhang (2022) observes economic variables in less developed countries, as compared to developed ones, are less sensitive to climate risks because of the lack of awareness to climate risks and clear climate related policies. To explore whether the effect of climate change vulnerability on FDI inflows differs with income levels of countries, we use IMF categorization and divide sample countries into three subgroups: high-income, middle-income and low-income countries. We re-estimate Eq. (1) one-by-one for all three sub-samples. As shown in the Table 3, the coefficients of climate change vulnerability variable are significant only for high-income and middle-income countries, but not for low-income countries. On the contrary, market size is positively significant for low-income countries. These results suggest that FDI inflows for low-income countries are not driven by climate related risks but by their market size. One potential explanation is that MNCs are more tolerant to risks in underdeveloped countries. MNCs may be more accustomed to dealing with political and economic instability, and therefore may be more willing to take on additional risks associated with climate change.

5.2. *Previous climate related risks of a country and FDI inflows*

MNEs' managers are likely to consider a country's previous vulnerability to climate related risks while making FDI location decisions. To check this possibility, we examine whether current years' FDI inflows are associated with previous years' values of vulnerability index. For doing so, we lag climate vulnerability index by one-period, two-periods, and three-periods. As shown in Table 4, lagged values of climate vulnerability index enter negative and significant with FDI inflows. These results imply that MNCs consider a country's previous history of climate vulnerability while making FDI decisions.

5.3. *Robustness checks*

In additional robustness tests, we use alternative definition of climate change vulnerability and add additional control variables in the model.

As an alternative measure of countries' climate change vulnerability, we create a dummy variable equal to one for 43 sample countries that are the members of Vulnerable Twenty (V20) Group and zero otherwise. V20 Group is a dedicated cooperation initiative of 55 nations that are systemically vulnerable to climate change. As shown in Table (5), the dummy variable representing V20 Group members enters negative and significant implying that these countries received lower FDI inflows as compared to their counterparts.

MNEs managers consider country risks related to institutional environment and government economic policies while making FDI destination decisions (Cheng and Kwan, 2000; Leahy and Montagna, 2001; Bjorvatn and Eckel, 2006; Alfaro et al., 2008; Julio and Yook, 2016). We add governance and policy uncertainty indicators as additional variables to control these effects. For doing so, first we re-estimate Eq. (1) by including six World Governance Indicators including voice and accountability, political stability, government

Table A1
List of countries. This table lists the countries included in the sample.

Albania	Dominican Republic	Lithuania	Serbia
Algeria	Ecuador	Luxembourg	Sierra Leone
Angola	El Salvador	Madagascar	Singapore
Armenia	Equatorial Guinea	Malaysia	Slovenia
Australia	Estonia	Maldives	Solomon Islands
Austria	Ethiopia	Mali	South Africa
Azerbaijan	Fiji	Malta	Spain
Bahamas	Finland	Mauritania	Sri Lanka
Bahrain	France	Mauritius	Sudan
Bangladesh	Gabon	Mexico	Sweden
Barbados	Gambia	Moldova, Republic	Switzerland
Belarus	Georgia	Mongolia	Syrian Arab Republic
Belgium	Germany	Montenegro	Tajikistan
Benin	Ghana	Morocco	Tanzania
Bhutan	Greece	Mozambique	Thailand
Bosnia and Herzegovina	Guatemala	Myanmar	Timor-Leste
Botswana	Guinea	Namibia	Togo
Brazil	Guinea-Bissau	Nepal	Tonga
Brunei Darussalam	Guyana	Netherlands	Tunisia
Bulgaria	Haiti	New Zealand	Turkey
Burkina Faso	Honduras	Nicaragua	Uganda
Burundi	Hungary	Niger	Ukraine
Cambodia	Iceland	Nigeria	United Arab Emirates
Cameroon	India	Norway	United Kingdom
Canada	Indonesia	Oman	United States
Central African	Iran	Pakistan	Uruguay
Chad	Iraq	Panama	Vanuatu
Chile	Ireland	Papua New Guinea	Venezuela
China	Israel	Paraguay	Viet Nam
Colombia	Italy	Peru	Yemen
Comoros	Jamaica	Philippines	Zambia
Congo	Japan	Poland	Zimbabwe
Democratic republic of Congo	Jordan	Portugal	
Costa Rica	Kazakhstan	Qatar	
Cote d'Ivoire	Kenya	Romania	
Croatia	Kuwait	Russian Federation	
Cyprus	Kyrgyzstan	Rwanda	
Czech Republic	Latvia	Samoa	
Denmark	Lebanon	Saudi Arabia	
Djibouti	Lesotho	Senegal	

effectiveness, regulatory quality, rule of law and control of corruption, from World Bank one-by-one. Second, we include Economic Policy Uncertainty (EPU) index of Baker et al. (2016) which is available for 20 countries as an additional control variable.

As shown in Table (6), climate vulnerability index enters negative and significant even after controlling for governance and EPU indexes. Consistent with intuition, political stability, regulatory quality and rule of law variables are positively associated with FDI inflows. Together, these results confirm that our results are not driven by omitted variable bias.

As another robustness test, we estimate a dynamic panel system generalized method of moments (GMM) regression model (Arellano and Bover, 1995; Blundell and Bond, 1998). System GMM estimator helps to control for the bias due to persistence in dependent variable, unobserved fixed effects, and endogeneity between dependent and independent variables. We may suspect bias due to these factors in our model. For instance, FDI inflows persist because of long-term international business relationships where firms keep expanding, reinvesting, or reorganizing (Eichengreen et al., 2018; Ng et al., 2022). Likewise, country-level fixed characteristics, such as culture or stable formal institutions, have not been observed in our model. Finally, the climate change vulnerability might be endogenous; on the one hand, higher vulnerability reduces FDI inflows, while, on the other hand, higher FDI inflows may contribute to CO2 emissions thereby increasing the climate vulnerability. Likewise, GDP growth is also endogenous; higher economic growth attracts FDI inflows while higher FDI inflows would further increase the GDP growth.

Results of system GMM regressions together with diagnostics tests are reported in Table 7. We use two period lags of dependent variable as explanatory variables as the p-value of AR(2) was not insignificant with one period lag. We assume climate vulnerability and GDP growth as endogenous variables and use their one period lag together with lagged values of Log (FDI inflows) as instruments.

As shown in the Model (2), Table 7, system GMM diagnostics tests also validate the use of system GMM estimator. For instance, the estimated values of coefficients of lagged FDI inflows variables with GMM estimator lie between their estimated values with panel fixed effects and pooled OLS estimators. Likewise, AR(1) is significant while AR(2) is insignificant. Finally, consistent with the advice of Roodman (2009), the models include year fixed-effects dummies and the number of instruments is lower than the number of countries. Climate vulnerability index still enters negative and significant in the system GMM regressions further validating the main results.

Table A2
Variable definitions. This table presents the definitions of main variables.

Variable	Measurement	Data source
Dependent variable		
Log(FDI inflows)	Log(FDI inflows) is equal to the natural log of annual foreign direct investment inflows of a country.	World Development Indicators, World Bank
Main explanatory variables		
Climate Vulnerability	Climate Vulnerability Index from Notre-Dame Global Adaptation Initiative (ND-GAIN). This index captures a country's vulnerability to climate change based on a range of factors, including a country's exposure to climate hazards (such as floods, droughts, and extreme temperatures), its sensitivity to the effects of climate change (such as changes in precipitation patterns and sea level rise), and its capacity to adapt to these changes. Higher values of the index represent higher climate vulnerability and vice versa.	Notre-Dame Global Adaptation Initiative (ND-GAIN)
Climate preparedness	Climate Preparedness Index from Notre-Dame Global Adaptation Initiative (ND-GAIN). This index captures a country's climate preparedness across economic, governance and social dimensions. More prepared countries have ease of doing business, better institutional framework, higher education level and a culture of innovation.	
Control variables		
GDP growth	Equals the year-on-year growth in nominal gross domestic product (GDP) of a country.	
Inflation	Equals annual percentage change in consumer goods prices in a country.	
Trade openness	Trade openness= (imports+exports)/GDP. Imports, exports and GDP (i.e, gross domestic product) are measured at annual frequency for each country.	
Labor Force	The labor force participation rate, referred as the proportion of individuals aged 15–64 who are currently engaged in the labor force.	World Development Indicators, World Bank
Market size	Equals the natural log of total population, measured annually for each country.	
Economic Policy Uncertainty	EPU index created by Baker, Bloom, and Davis (2016). The index measures the level of uncertainty in economic policy that is based on news articles. The index is computed using a text-based approach that analyzes the frequency of specific terms related to economic policy, uncertainty, and the future in major newspapers of a country. The higher the EPU index, the greater the degree of uncertainty and vice versa.	Baker, Bloom, and Davis (2016)
Voice and Accountability	The extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.	World Governance Indicators, World Bank
Political Stability and Absence of Violence/Terrorism	The likelihood of political instability and/or politically motivated violence, including terrorism.	
Government Effectiveness	The quality of public services, the degree of bureaucracy, and the competence of civil servants in formulating and implementing policies.	
Regulatory Quality	The degree to which regulations are transparent, effective, and fairly enforced, as well as the government's commitment to enforcing regulations.	
Rule of Law	The extent to which agents have confidence in and abide by the rules of society, and the quality of contract enforcement, property rights, the police, and the courts.	
Control of Corruption	The degree to which public power is exercised for private gain, including petty and grand corruption, and the effectiveness of anti-corruption efforts.	

Table A3
Summary of the literature regarding determinants of FDI. This table summarizes the literature on the determinants of FDI inflows.

Variable	Paper	Relationship with FDI inflows
GDP growth	Asamoah et al. (2016) and (Nguyen and Lee, 2021)	(+) Growing economies attract higher FDI inflows
Inflation	Asamoah et al. (2016) and (Nguyen and Lee, 2021)	(-) Higher inflation results in lower FDI inflows
Trade openness	Asiedu (2002) andAsongu et al. (2018)	(+) Higher trade is associated with more FDI inflows
Labor force	Nguyen and Lee (2021) and (Nguyen and Lee, 2021)	(+) Labor availability increase FDI inflows
Market size	Resmini (2000)	(+) Larger markets attract higher FDI inflows
Economic Policy Uncertainty	Nguyen and Lee (2021)	(-) Higher policy uncertainty reduces FDI inflows
Governance Indicator	Gani (2007) andQuang et al. (2022)	(+) Better governance increases FDI inflows

In the above analysis, we utilized the logarithm of FDI inflows as the dependent variable. However, a significant drawback of this measure is that it fails to capture the FDI retained by a country. For instance, if a country has a high influx of FDI, but also experiences significant outflows of FDI, the net FDI inflows may be considerably lower. This indicates that the country is not retaining as much foreign investment as it is receiving. To overcome this limitation, we employed the net FDI inflows as an alternative dependent variable. As shown in Table 8, the climate vulnerability index has a significant negative association with net FDI inflows, suggesting that net FDI retained by countries decreases with higher vulnerability to climate change. These results are in line with the main findings and again confirm our hypothesis. Interestingly, the interaction term, though positive, is not significant with net FDI inflows. These findings, combined with the above main results, indicate that while climate preparedness may be a factor in attracting foreign investments, it may not be as effective in retaining them over time.

6. Conclusion

This study aims to gauge the impact of climate vulnerability on FDI inflows. Employing data from 152 countries over the period 1996–2019, we find a strong negative association between climate change vulnerability and FDI inflows. However, the climate preparedness moderates this negative relationship; that is, the negative association weakens for countries that are more prepared in terms of economic, governance and social environment to cater the adverse effects of climate change. We also observe climate vulnerability is not a significant factor for low-income countries, where market size is the main driver of FDI inflows.

Our empirical findings have important implications for countries and MNEs. First, they help to understand another channel, foreign capital, through which climate change adversely affects the economy. As foreign capital plays an important role in economic development, countries should try to manage climate risk so that adverse consequences in terms of receipts of foreign capital can be avoided. Enhancing the economic, institutional, and social environment can help countries mitigate climate risks and maintain a favorable environment for foreign capital investment. Second, MNEs must consider climate risk as a crucial factor when pursuing internationalization, and implementing a comprehensive risk management strategy that addresses climate risks can increase their chances of success in global markets. Failing to account for climate risks could result in significant financial and reputational losses, making it imperative for MNEs to prioritize climate risk management in their international operations.

Future research can explore the connection between MNEs' experience with climate-vulnerable countries and their investment patterns in regions that are susceptible to the adverse effects of climate change.

CRediT authorship contribution statement

All authors contributed equally to the manuscript.

Data Availability

Data will be made available on request.

Appendix A

See Table A1–A3.

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