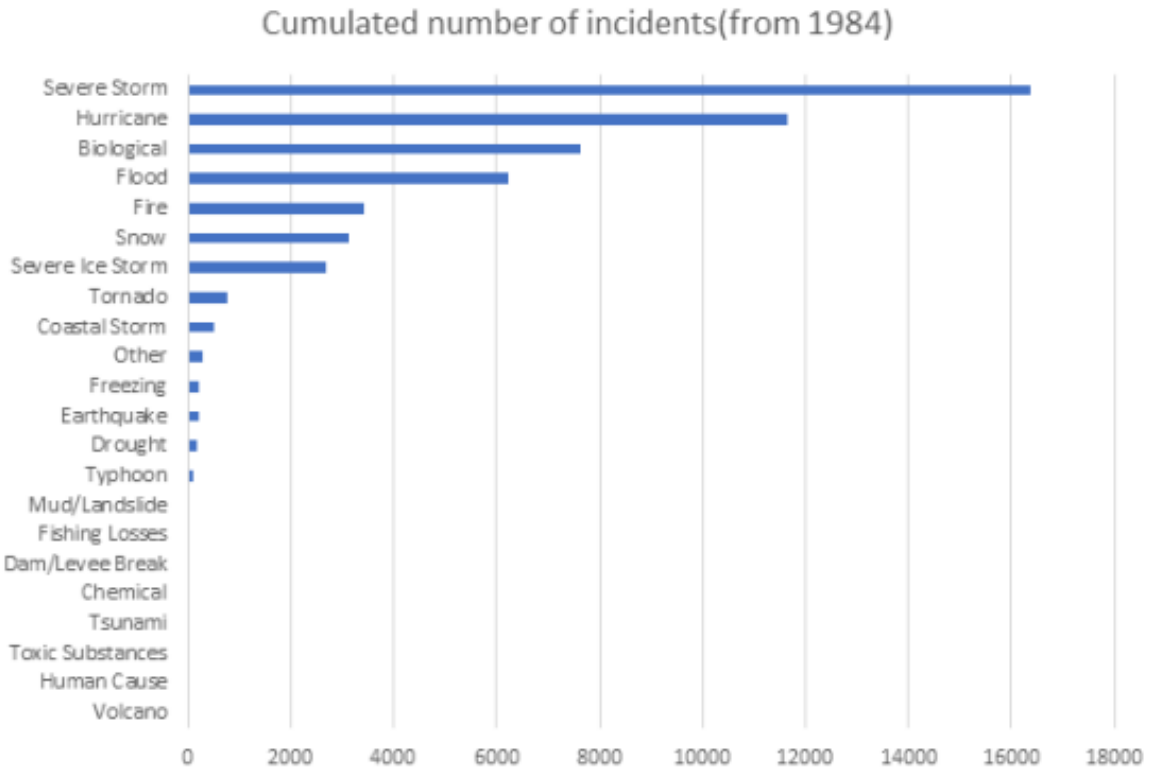
Online Appendix

Climate Change, Bank Fragility, and Systemic Risk

Figures

Figure O1: Number of climate disaster incidents
This figure shows the number of climate disaster incidents since 1984. The data is from FEMA.



Tables

Table O1: Variable Definition
All variables are measured at quarterly frequency.

Variable	Definition	Source
MES	MES is a systemic measure proposed by Acharya, Pedersen, Philippon, and Richardson (2017). It is defined as the bank's stock returns when the market has the worst stock returns at the 5% level.	CRSP
ΔCoVaR	ΔCoVaR is a systemic measure proposed by Adrian and Brunnermeier (2016). It is the difference between the financial system's value-at-risk conditional on bank i being distressed at the 5% level and financial system's value-at-risk conditional on bank i being in its median state.	CRSP
Sea level rise	Sea level rise exposure set by NOAA's sea level rise "intermediate" scenario in year 2040. The fraction of matched at the city-level using NAA data.	NOAA & NAA
Climate disaster	The number of climate disasters declaration (flood, severe storms, hurricanes, fire, snow, drought, tornado, etc) by state and year.	FAMA
Environmental and climate policy uncertainty	The indices constructed by Noailly, Nowzohour, and van den Hauvel (2022). The indices analyze 15 million news articles extracted from the archives of ten U.S. newspapers using machine learning technique.	Noailly, Nowzohour, and van den Hauvel (2022)
Firm-level environmental risk	A firm-level environmental risk proxy constructed by Hassan, Hollander, van Lent, Tahoun (2019).	Hassan, Hollander, van Lent, Tahoun (2019)
Ln(Assets)	Banks of different sizes have different risks. To control for this possibility, we proxy for bank size by natural logarithm of bank assets.	Call Report
Bank Capital	More leveraged banks are more likely to experience a larger variation in equity values given a shock. We proxy for bank capital by the ratio of bank equity to assets.	Call Report
Profitability (ROA)	Return on assets is a measure for Profitability common in banking industry. We proxy for bank profitability by a bank's return-on-assets variables to total assets.	Call Report
Loan-to-Assets	We proxy for loan-to-assets as total loans scaled by assets.	Call Report
Loan Growth	Loan growth is the growth rate of loan-to-assets ratio.	Call Report
Loan Loss Provisions-to-Assets	We proxy for loan loss provisions-to-assets as total loan loss provisions scaled by assets.	Call Report
Liquidity-to-Assets	We proxy for liquidity-to-assets as the sum of cash and treasury securities scaled by assets.	Call Report
Deposit-to-Assets	We proxy for deposit-to-assets as total deposits scaled by assets.	Call Report
Non-interest income-to-Assets	We proxy non-interest income-to-assets as the ratio of noninterest income to assets.	Call Report

Table O2: State-led climate change adaptation plans (As of March 2021)

State	Adaptation plans date
Alabama	No state-led adaptation plan finalized.
Alaska	Jan-2010
Arizona	No state-led adaptation plan finalized.
Arkansas	No state-led adaptation plan finalized.
California	2009
Colorado	Jul-2018
Connecticut	2013
District of Columbia	15-Nov-2016
Delaware	2-Mar-2015
Florida	15-Oct-2008
Georgia	No state-led adaptation plan finalized.
Hawaii	State adaptation planning underway
Idaho	No state-led adaptation plan finalized.
Illinois	No state-led adaptation plan finalized.
Indiana	No state-led adaptation plan finalized.
Iowa	No state-led adaptation plan finalized.
Kansas	No state-led adaptation plan finalized.
Kentucky	No state-led adaptation plan finalized.
Louisiana	No state-led adaptation plan finalized.
Maine	Feb-2010
Maryland	Jul-2008
Massachusetts	2011
Michigan	State adaptation planning underway
Minnesota	State adaptation planning underway
Mississippi	No state-led adaptation plan finalized.
Missouri	No state-led adaptation plan finalized.
Montana	Aug-2020
Nebraska	No state-led adaptation plan finalized.
Nevada	No state-led adaptation plan finalized.
New Hampshire	Mar-2009
New Jersey	State adaptation planning underway
New Mexico	No state-led adaptation plan finalized.
New York	2010
North Carolina	2-Jun-2020

North Dakota	No state-led adaptation plan finalized.
Ohio	No state-led adaptation plan finalized.
Oklahoma	No state-led adaptation plan finalized.
Oregon	Dec-2010
Pennsylvania	2011
Rhode Island	2-Jul-2018
South Carolina	No state-led adaptation plan finalized.
South Dakota	No state-led adaptation plan finalized.
Tennessee	No state-led adaptation plan finalized.
Texas	No state-led adaptation plan finalized.
Utah	No state-led adaptation plan finalized.
Vermont	State adaptation planning underway
Virginia	15-Dec-2008
Washington	Apr-2012
West Virginia	No state-led adaptation plan finalized.
Wisconsin	State adaptation planning underway
Wyoming	No state-led adaptation plan finalized.

Table O3: Correlation

This table presents correlations of the main variables used in this paper. The sample data covers U.S. banks during the period from January 1990 to December 2016. All variables in this table are measured at the quarterly frequency. All the continuous variables are winsorized at 1% and 99% percentile.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) MES	1.0000														
(2) ΔCoVar	0.3026	1.0000													
(3) Sea level rise	0.0185	0.0409	1.0000												
(4) Climate disaster	0.0010	0.1135	0.0703	1.0000											
(5) Environmental and climate policy uncertainty	0.3805	0.3176	-0.1975	0.1175	1.0000										
(6) Firm-level environmental risk	0.1908	0.0470	-0.0054	-0.0220	0.1602	1.0000									
(7) Ln(Assets)	-0.1271	0.1928	0.1102	0.0222	0.0219	0.0876	1.0000								
(8) Ln(Assets)^2	-0.1239	0.1843	0.1174	0.0189	0.0208	0.0945	0.9984	1.0000							
(9) Bank Capital	-0.1392	0.1502	-0.0765	0.0843	0.1806	-0.0569	-0.0225	-0.0294	1.0000						
(10) Profitability (ROA)	-0.3969	-0.0886	0.0806	0.0373	-0.3359	-0.1253	0.0848	0.0833	0.2354	1.0000					
(11) Loan-to-Assets	0.1243	0.0325	-0.0763	-0.0223	0.0184	-0.0875	-0.4150	-0.4220	-0.0553	-0.0577	1.0000				
(12) Loan Growth	-0.1135	-0.0119	0.0369	0.0385	-0.1164	-0.0933	-0.0399	-0.0390	0.2356	0.1899	0.2280	1.0000			
(13) Loan Loss Provisions-to-Assets	0.4124	0.1451	-0.0477	-0.0543	0.2600	0.1545	-0.0010	0.0009	-0.1135	-0.4822	0.1334	-0.1619	1.0000		
(14) Liquidity-to-Assets	-0.0190	-0.0556	-0.0826	0.0402	0.1560	0.1071	0.0838	0.0899	0.1290	-0.0567	-0.2334	-0.0269	0.0715	1.0000	
(15) Deposit-to-Assets	0.0783	-0.0534	-0.1283	0.0024	0.0278	-0.0552	-0.6151	-0.6226	-0.0135	-0.1082	0.6723	0.1087	0.0814	-0.1503	1.0000
(16) Non-interest income-to-Assets	-0.0941	0.0002	0.0836	0.0304	-0.0951	0.0373	0.3188	0.3225	0.2634	0.3916	-0.4671	0.0434	0.0329	0.1922	-0.5065

In Table O4-O6, we conduct robustness tests. First, we conduct different sets of tests using additional measures. Table O4 provides the results of using long-term climate change exposure and climate regulatory stringency. The long-term climate change is proxied by using the average of the previous 5 years of climate change exposure at the firm level. The measure of long-term exposure is obtained from Hassan, Hollander, van Lent, and Tahoun (2019). Given the long-run and non-diversifiable nature of climate risk, the measure of long-term climate change exposure captures long-term exposure to climate change. To proxy the climate regulatory stringency, the U.S. Environmental Protection Agency (EPA) enforcement data is employed. We count the number of compliance and enforcement actions conducted by each state under the Clean Water Act and Clean Air Act. The number of enforcements is scaled by the total number of facilities that are subject to EPA regulations in a given state in a given year, as in Seltzer et al. (2020). In Table O4, we find that all coefficients of long-term climate exposure measures and climate regulatory stringency are significantly positive. Next, to rule out some potential omitted variables, we include additional control variables and extra fixed effects. The test results are reported in Table O5. Lastly, we compare big banks and small banks. For example, big banks and small banks typically adopt different approaches of risk taking, have different assessment abilities, and have different levels of bank capital. To address the potential impact of these differences, we implement sub-sample analyses. As shown in Table O6, the results of these analyses are consistent with our baseline results.

Table O4: Additional measures
This table reports the regression results of bank fragility on climate change and controls. The data are quarterly and extend from January 1990 to December 2016. The dependent variable has a lead of one period with respect to the independent variables. Standard errors are clustered at the firm level. *t*-statistics are reported in parentheses. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level, respectively.

Panel A: Long-term exposure

	(1) MES_{t+1}	(2) $\Delta CoVar_{t+1}$
Long-term exposure	1.0507***	0.1086***
	(4.52)	(3.78)
Ln(Assets)	-0.0174	0.0029
	(-0.80)	(0.83)
$Ln(Assets)^2$	0.0006	-0.0001
	(0.93)	(-1.07)
Bank Capital	-0.1503***	-0.0050
	(-4.44)	(-1.04)
Profitability (ROA)	-1.0581***	-0.0890***
	(-6.08)	(-3.70)
Loan-to-Assets	0.0761***	0.0090***
	(7.47)	(5.37)
Loan Growth	-0.0263***	-0.0054***
	(-3.34)	(-4.10)
Loan Loss Provisions-to-Assets	1.4826***	0.2371***
	(7.23)	(7.71)
Liquidity-to-Assets	-0.0607***	-0.0091***
	(-3.04)	(-3.16)
Deposit-to-Assets	-0.0227**	-0.0024*
	(-2.39)	(-1.76)
Non-interest income-to-Assets	0.1344	0.0089
	(1.43)	(0.53)
Firm fixed effects	Yes	Yes
Time fixed effects	Yes	Yes
Cluster by firm	Yes	Yes
Observations	6954	6954
Adjusted R^2	0.3315	0.6822

Panel B: Climate regulatory stringency

	(1) MES_{t+1}	(2) $\Delta CoVar_{t+1}$
Climate regulatory stringency	0.0007***	0.0002***
	(2.66)	(4.99)
Ln(Assets)	-0.1526***	-0.0088**
	(-6.81)	(-2.10)
$Ln(Assets)^2$	0.0052***	0.0003**
	(7.20)	(2.52)
Bank Capital	-0.0421**	-0.0073
	(-2.28)	(-1.54)
Profitability (ROA)	0.0244	0.0066
	(0.21)	(0.95)
Loan-to-Assets	-0.0018	0.0029**
	(-0.26)	(2.05)
Loan Growth	-0.0024	-0.0011
	(-0.51)	(-1.63)
Loan Loss Provisions-to-Assets	0.7591***	-0.0029
	(3.63)	(-0.27)
Liquidity-to-Assets	0.0173	-0.0009
	(1.54)	(-0.63)
Deposit-to-Assets	0.0097**	0.0010
	(2.30)	(1.25)
Non-interest income-to-Assets	0.0677	-0.0005
	(0.76)	(-0.07)
Firm fixed effects	Yes	Yes
Time fixed effects	Yes	Yes
Cluster by firm	Yes	Yes
Observations	4644	4644
Adjusted R^2	0.4688	0.9652

Table O5: Omitted variables

Panel A reports the regression results on sea level rise. Panel B reports the regression results on environmental policy risk. The dependent variable has a lead of one period with respect to the independent variables Standard errors are clustered at the bank level. *t*-statistics are reported in parentheses. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level, respectively.

Panel A: Sea level rise

	(1)	(2)	(3)	(4)	(5)	(6)
	MES_{t+1}	MES_{t+1}	MES_{t+1}	$\Delta CoVar_{t+1}$	$\Delta CoVar_{t+1}$	$\Delta CoVar_{t+1}$
Sea level rise	0.0038*	0.0041**	0.0045***	0.0005***	0.0006***	-0.0008
	(1.91)	(2.03)	(3.30)	(3.03)	(3.22)	(-1.46)
Financial crisis		0.0169***	0.0151***		0.0019***	0.0020***
		(16.19)	(13.92)		(16.08)	(9.29)
Bank competition			0.1115***			0.0025
			(7.02)			(0.47)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	No	Yes	Yes	No
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes	Yes
Observations	36820	36820	36835	36820	36820	36835
Adjusted R^2	0.3709	0.3801	0.2589	0.8694	0.8711	0.4242

Panel B: Environmental and climate policy uncertainty

	(1) MES_{t+1}	(2) MES_{t+1}	(3) MES_{t+1}	(4) $\Delta CoVar_{t+1}$	(5) $\Delta CoVar_{t+1}$	(6) $\Delta CoVar_{t+1}$
Environmental and climate policy uncertainty	0.0210***	0.0199***	0.0153***	0.0016***	0.0015***	0.0018***
	(28.25)	(27.31)	(18.16)	(19.10)	(18.28)	(7.59)
Financial crisis		0.0097***	0.0109***		0.0014***	0.0015***
		(9.41)	(10.27)		(12.36)	(7.07)
Bank competition			-0.0239			-0.0117**
			(-1.29)			(-2.16)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	No	Yes	Yes	No
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes	Yes	Yes
Observations	36820	36820	36835	36820	36820	36835
Adjusted R^2	0.4132	0.4161	0.2790	0.8729	0.8737	0.4278

Table O6: Heterogeneity across banks

This table reports the regression results of bank fragility on climate change and controls. The data are quarterly and extend from January 1990 to December 2016. The dependent variable has a lead of one period with respect to the independent variables. Standard errors are clustered at the firm level. *t*-statistics are reported in parentheses. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level, respectively.

Panel A: Big Banks vs. Small Banks

	Big Banks		Small Banks	
	(1)	(2)	(3)	(4)
	$\Delta CoVar_{t+1}$	MES_{t+1}	$\Delta CoVar_{t+1}$	MES_{t+1}
Firm-level environmental risk	0.2101***	1.3147***	0.0807*	1.2089***
	(3.76)	(3.46)	(1.95)	(3.16)
Controls	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes
Observations	2294	2294	2313	2313
Adjusted R^2	0.4873	0.2868	0.8120	0.4328

Panel B: High bank capital vs. Low bank capital

	High Capital		Low Capital	
	(1)	(2)	(3)	(4)
	$\Delta CoVar_{t+1}$	MES_{t+1}	$\Delta CoVar_{t+1}$	MES_{t+1}
Firm-level environmental risk	0.1183**	0.7942**	0.0644	0.8211**
	(2.44)	(2.04)	(1.39)	(2.28)
Controls	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Cluster by firm	Yes	Yes	Yes	Yes
Observations	2288	2288	2311	2311
Adjusted R^2	0.7088	0.3329	0.7132	0.4701

References

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