Rare Disasters and Bank Lending

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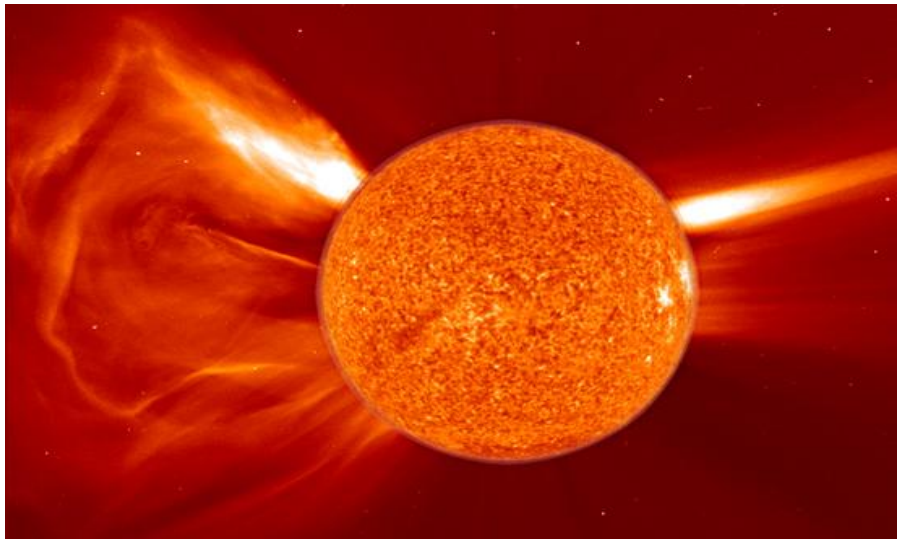
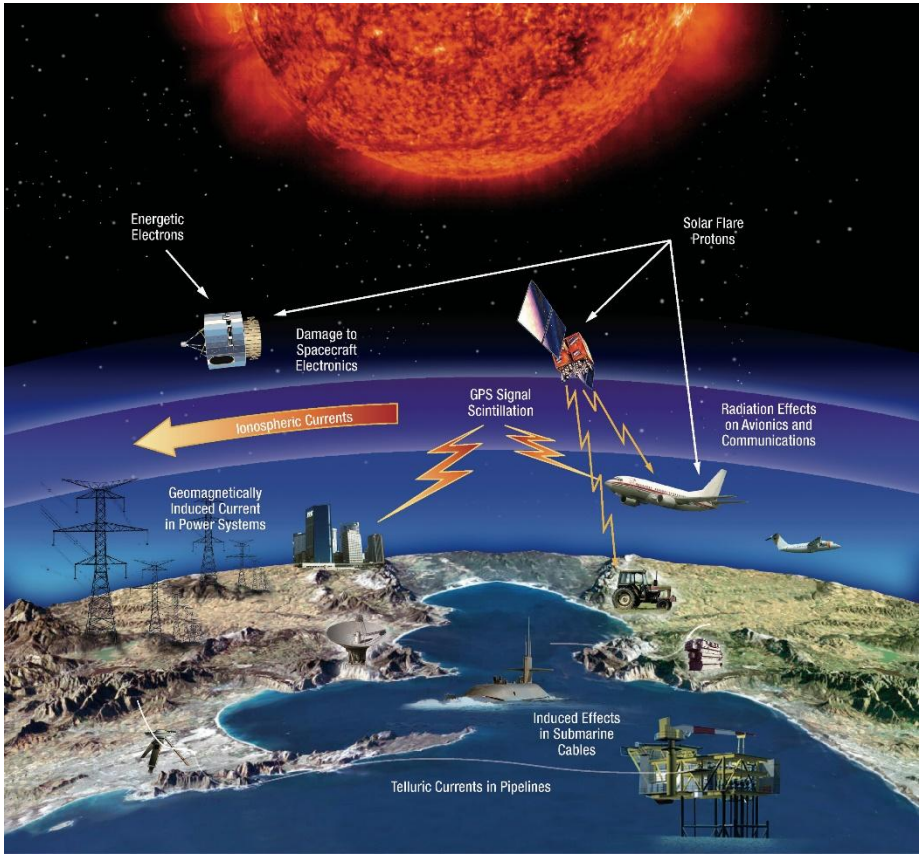
Motivation – Solar Storms



Solar Storms can significantly impact earth. They can disrupt satellites, power grids, and communication systems. While they don't directly harm humans, the indirect effects can be substantial.



Solar Storm

- A solar storm is a disturbance on the Sun, which can emanate outward across the heliosphere, affecting the entire Solar System, including Earth and its magnetosphere.

- It is the cause of space weather in the short-term with long-term patterns comprising space climate.

Anecdotal Evidence

- The *most extreme solar storm* on record, **the Carrington Event** of 1859, led to widespread telegraph failure and would have cost $0.6–$2.6 trillion in today's terms, based on the number of people affected in the U.S. alone.

- In 1989, the **Hydro-Québec blackout** was initiated by a powerful solar storm during which *six million people* were left without power, costing several billions of dollars.

- The **Halloween Solar Storm** of 2003, damaged 47 satellites, including at least 10 satellites needing extensive repair and total damages of $10 to $50 million

Motivation

- As the global economy depends more and more
  - on digital infrastructure* (binary system or logic signal)
  - connected networks
  - energy supply

the *importance of understanding* the systemic vulnerabilities in light of exogenous risks is elevated.

- The threat posed by extreme solar weather has become a source of global economic risk.

- While the economic dimensions of climate-related disruptions have been studied extensively, the role of solar storms has been underexplored.

*Analog electronics prior **with a continuously variable signal**, in contrast to digital electronics.

Motivation – Projections

- According to a systemic risk scenario *published by Lloyd's*, - a *hypothetical solar storm* - could expose the global economy to cumulative losses of up to $2.4 trillion over a five-year period.
  - Expected immediate losses reaching $17 billion (Lloyd's, 2024).

- The projected losses range from $1.2 trillion in a low-impact scenario to a staggering $9.1 trillion in a severe storm event, equivalent to a Global GDP contraction of 0.2% to 1.4%.

- Researchers at the *University of Cambridge* estimated that a severe solar storm could cost the United States (US) tens of billions of dollars per day due to widespread power blackouts.
  - More than half of the losses stemming from indirect economic impacts

What is this study about

- The study *address this gap* by investigating whether solar geomagnetic storms (as a form of physical climate risk) have a measurable impact on syndicated loan pricing in global credit markets.

- Our work investigates whether solar storms can act as **systemic financial shocks**
  - amplifying perceived risk
  - tightening credit conditions

especially when *physical infrastructure disruptions* elevate borrower (i) or economic uncertainty (ii).

- By examining whether lenders incorporate such risks into syndicated loan pricing, our study examines a previously unmeasured source of risk in global capital flows.

- Solar-induced disturbances, to communications (i), data centers (ii), and power systems (iii), could elevate financing costs in affected regions, with potential implications for sovereign risk premia and investor behavior

Literature – Climate Risk Transitions from Borrowers to Banks

- Laeven and Popov (2023) show that a carbon tax generates banks to restrict lending to carbon intensive sectors.

- Laeven and Popov (2023), Ehlers et al. (2022) and Reghezza et al. (2022) demonstrate that banks price brown firms at a higher interest rate compared to green borrowers.

- Kacperczyk and Peydró (2022) uncover that post commitment to decarbonize, entails that banks cut lending to polluting firms.

- Degryse et al. (2023) show that green banks are more likely to offer them preferential terms,
  - particularly when firms hold stronger ESG credentials.

Literature – Solar Storms

- Jevons (1878, 1879, 1882) in three seminal articles suggested that sunspot activity might be a cause of business cycles.
- Chizhevsky (1938, 1976) extended the "Jevons hypothesis"*
- Garcia-Mata and Shaffner (1934) empirically explored it, finding strong evidence of solar influences on economic variables.
- Tasnim et al. (2016) and Daglis et al. (2019) revisited the Jevons hypothesis using modern data sources.
- *No empirical study* has so far quantified the financial impact of solar storms on international credit markets at the firm level, a gap this paper addresses.

* improvements in fuel efficiency tend to increase (rather than decrease) fuel use

Findings

•We find that solar storms lead to *statistically and economically significant* increases in loan spreads.

- •The effects are more substantial for firms in infrastructure-sensitive industries (1) and in high-latitude regions* (2).

•These results support the *theoretical prediction of solar-induced fragility* and highlight the importance of *integrating* solar climate risk into the broader climate risk framework.

•We further document *adjustments* in syndicate structure (i) and leadership dynamics (ii) in response to heightened systemic uncertainty.

•Our results reveal that solar storms are priced into credit markets, through elevated risk premia,

- •expanding the conceptualization of climate-related financial risks.

•areas located far from the equator, generally between 60 and 90 degrees latitude in both the Northern and Southern Hemispheres

Contribution

- The study introduces solar storms as a *novel, exogenous source* of climate-related financial risk and demonstrates their measurable impact on syndicated loan spreads.

- It provides the first *causal evidence* linking solar activity to credit risk perception in international markets.
  - It uses high-frequency space weather data and loan-level observations in a panel-DiD framework.

- It shows that infrastructure fragility
  - especially in power and communication systems

has *immediate implications* for cross-border lending.

- It validates solar flare activity *as a complementary proxy* for solar risk and confirms the robustness of our results.

- This study contributes to the literature on climate-related financial risks,
  - Broadens the taxonomy of physical risk to include exogenous space-weather events.

Hypothesis Development

- Syndicated loan spreads are expected to increase in response to heightened solar activity,
  - Particularly when lenders anticipate that operational disruptions could impair firms' ability to maintain liquidity or complete ongoing projects.

Hypothesis 1. *Syndicated loan spreads increase following periods of intense solar activity.*

- Geomagnetic storms represent a distinct form of physical risk, i.e. exogenous to borrowers but still capable of disrupting vital infrastructure like GPS, telecommunications, and energy distribution.
  - These technologies underpin modern corporate operations and financial systems

Hypothesis 2. *The effect of solar activity on syndicated loan spreads is stronger for firms in infrastructure-sensitive sectors.*

Hypothesis Development (‘cont)

Hypothesis 3. *Solar storm risk*
i) affects the structure of lending syndicates
ii) affects the distribution of risk across participating banks
leading to wider spreads (i) and greater lender dispersion (ii) in high-risk contexts.

- In sum, we position solar storms as an under-appreciated channel through which exogenous environmental shocks are priced in global debt markets.

Sample Construction

- *DealScan Database*: Syndicate Loans
- *SEC Filings*: Firms' climate risk data
- Financial News Outlets
- Compustat Global Fundamentals Database: Match borrower financial characteristics to the facility-level loan data.
- Our final dataset spans the period from 1995 to 2021 and includes 34,737 syndicated loan facilities issued to 5,076 non-financial firms.

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Firm Level Climate Risk Measurement

- We employ a ***climate risk index*** *at the firm level* introduced by Sautner, Van Lent, Vilkov, and Zhang (2023).
  - It is designed to *capture the multifaceted risks,* companies encounter due to climate change

- The ***climate risk index*** *quantifies* company-specific climate-related considerations.
  - It *showcases* ***significant variability*** *across different companies* and over time, reflecting the *unique climate challenges* each firm faces.

- The index takes a comprehensive approach, *addressing various dimensions* of climate risk at the firm level,

-physical risks (i),
-regulatory risks (ii)
-transitional risks (iii).

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Methodology – Geomagnetic Storms

- Accurate measurement of "geomagnetic disturbances intensity" is a critical element in analyzing the solar storms financial effects.
  - The **Disturbance Storm Time (*Dst*) index** has become the most recognized.

- *Dst* index is a measure of the globally averaged depression of the "Earth's magnetic field" that has been developed as a measure of the intensification of large scale current systems.

- *Dst* index, as emphasized by Temerin and Li (2006), is an *effective geophysical indicator of space weather fluctuations*, and it gives a complete picture of the electromagnetic responses to solar activity.

- *We use Dst* index data from NASA's Space Physics Data Facility and investigate **credit risk implications of solar storm for syndicated loan**.

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Methodology – Solar Flares

- We includes "Solar Flare" "ηλιακή έκλαμψη" activity as
  - a *complementary indicator* of "space-weather intensity" and
  - a robustness check for the observed financial effects.

- Solar flares are **intense bursts of radiation** coming from the sun's atmosphere.

- Whereas, the ***Dst* index** offers an integral measure of the Earth's geomagnetic response to an active space weather environment, a **solar flare** brings the pertinent and more proximate measure of the solar origin for space weather volatility.

- Solar flares can directly interfere with *satellite based systems*,
  - Radio Communications
  - GPS infrastructure

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Solar Storm Activity

- Solar activity is captured using three exogenous indicators.
- Our primary proxy, ***storm intensity***, is constructed as the *negative of the Dst geomagnetic index divided by 100*.
- This transformation ensures that higher values reflect more intense geomagnetic storms, consistent with the index's inverse scale.

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Descriptive Results (T1)

Variable	N	Mean	Median	SD	p25	p75
AllInDrawn ek	34,737	1.752	1.500	1.218	0.875	2.250
l storm intensity100	34,737	0.131	0.128	0.068	0.078	0.179
Vsw (Solar Wind Velocity)	34,737	434.248	429.533	42.434	414.356	452.911
ln sunspots	34,737	3.880	4.208	1.086	3.212	4.689
ln at l	34,737	13.250	13.497	1.244	12.378	14.276
rroa l	34,737	0.800	0.799	0.586	0.468	1.137
rbcr l	34,737	7.001	7.201	2.799	4.556	9.224
rlev l	34,737	11.480	10.861	8.218	7.025	14.152
wZ score bank	34,737	23.970	24.412	9.614	16.281	30.181
dummy NPL	34,737	0.005	0.000	0.067	0.000	0.000
MaturityYears	34,737	4.235	4.999	1.860	3.001	5.002
DealAmount bil	34,737	1.624	0.750	3.154	0.300	1.750
roa b	34,737	0.011	0.035	2.045	0.008	0.066
collateral b	34,737	0.713	1.000	0.453	0.000	1.000
leverage b	34,737	0.319	0.292	0.222	0.181	0.419
size b	34,737	8.389	8.393	1.721	7.263	9.581
tangibility b	34,737	0.320	0.256	0.245	0.113	0.495

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Explanation of Descriptive Stats

- The average storm intensity is 0.131, with an interquartile range of 0.078 to 0.179, spanning mild to severe disturbances.
- To further capture solar cycle dynamics, we include solar wind velocity (*vsw*)—which averages 434.2 km/s, and the natural logarithm of sunspot counts (*ln sunspots*), averaging 3.88.
- The average firm size, proxied by the log of total assets (*size b*), is 8.39, and mean profitability, measured by return on assets (*roa b*), is 1.1%.
- Borrowers display varying leverage levels (*leverage b* = 0.319 on average) and asset tangibility (*tangibility b* = 0.32).
- Approximately 71.3% of loans are secured (*collateral b*).
- The average loan maturity is approximately 4.24 years, with a wide range of durations across the sample. Facility size averages $1.62 billion (*DealAmount bil*),

Impact of Solar Storm Events on Syndicated Loan Spreads

VARIABLES	(1)	(2)	(3)
Solar_Storm_q $_{t-1}$	0.082***	0.098***	0.154***
	(0.019)	(0.019)	(0.023)
Size_l	-0.048***	-0.045***	-0.043***
	(0.003)	(0.003)	(0.003)
Roa_l	-0.082***	-0.080***	-0.081***
	(0.008)	(0.007)	(0.007)
Rbcr_l	-0.023***	-0.020***	-0.020***
	(0.002)	(0.002)	(0.002)
Lev_l	0.016***	0.016***	0.016***
	(0.000)	(0.000)	(0.000)
Z_score_l	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Dummy NPL	0.790***	0.783***	0.785***
	(0.048)	(0.049)	(0.049)
MaturityYears	0.067***	0.060***	0.057***
	(0.002)	(0.002)	(0.002)
DealAmount	0.010***	0.007***	0.006***
	(0.001)	(0.001)	(0.001)
Roa_b	-0.002	-0.001	-0.001
	(0.004)	(0.004)	(0.004)
Collateral_b	-0.414***	-0.416***	-0.400***
	(0.008)	(0.008)	(0.008)
Altman_Z_Score_b	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Leverage_b	1.023***	1.003***	0.972***
	(0.038)	(0.039)	(0.042)
Size_b	-0.219***	-0.219***	-0.224***
	(0.003)	(0.003)	(0.003)
Tangibility_b	0.034***	0.006	-0.153***
	(0.012)	(0.016)	(0.019)
Constant	2.707***	3.909***	3.981***
	(0.047)	(0.051)	(0.051)
Observations	34,737	34,737	34,737
R-squared	0.324	0.336	0.345
Year FE	YES	YES	YES

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Impact of Solar Storm Events on Syndicated Loan Spreads

The coefficient on *solar_storm_q3* is 8.2 basis points (bps)

- Adding sector fixed effects and partial controls in Column(2) increases the effect to 9.8 bps.

- Including comprehensive firm, bank, and facility-level controls, yields an effect of 15.4 bps.

- This progression highlights the stability and economic significance of the *solar storm treatment effect*.

- The **estimated increase in borrowing costs** following a major solar storm event corresponds to a cumulative additional interest expense of approximately $10.6 million per loan

Impact of Solar Storm Events – Alt Specifications

VARIABLES	(1) DealAmount	(2) DealAmount	(3) DealAmount
Solar_Storm_q $_{t-1}$	0.185***	0.179***	0.171***
	(0.055)	(0.054)	(0.054)
All_In_Drawn	0.131***	0.141***	0.122***
	(0.006)	(0.006)	(0.007)
Size_l	-0.031***		0.036
	(0.005)		(0.030)
Roa_l	-0.014		-0.034**
	(0.011)		(0.016)
Rbcr_l	-0.013***		-0.036***
	(0.003)		(0.010)
Lev_l	0.001		0.001
	(0.001)		(0.001)
Z_score_l	0.001***		0.012***
	(0.001)		(0.004)
Dummy NPL	0.929***		0.896***
	(0.165)		(0.161)
MaturityYears	-0.071***	-0.070***	-0.076***
	(0.006)	(0.006)	(0.006)
Roa_b	-0.013***	-0.011***	
	(0.004)	(0.004)	
Collateral_b	-0.193***	-0.186***	
	(0.013)	(0.012)	
Altman_Z_Score_b	-0.000**	-0.000**	
	(0.000)	(0.000)	
Leverage_b	0.930***	0.924***	
	(0.045)	(0.044)	
Size_b	0.992***	0.993***	
	(0.015)	(0.015)	
Tangibility_b	-1.609***	-1.567***	
	(0.097)	(0.095)	
Constant	-5.824***	-6.329***	1.244***
	(0.155)	(0.134)	(0.410)
Observations	34,737	34,737	34,737
R-squared	0.677	0.676	0.662
Firm Controls	YES	NO	YES
Bank controls	YES	YES	NO
Sector FE	YES	YES	NO
Firm FE	YES	YES	NO
Bank FE	YES	NO	YES

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Effects of Solar Storm on Loan Spreads (T3)

	(1) Nearest Neighbor	(2) Kernel Matching	(3) Stratification Matching
ATT Estimate	0.161***	0.110***	0.080***
	(0.055)	(0.023)	(0.020)
Constant	-3.718***	-3.718***	-3.718***
	(0.101)	(0.101)	(0.101)
Observations	34,737	34,737	34,737
Controls Included	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes
Common Support	Yes	Yes	Yes

All *three matching methods* yield statistically significant and economically meaningful ATT estimates:

16.1 bps using nearest neighbor,

11.0 bps with kernel

8.0 bps under stratification.

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Effects of Solar Storm on Loan Spreads (T3)

- The results are fully consistent with our baseline OLS findings and reinforce the causal interpretation by balancing observable covariates across treated and control observations.

- The *regression and matching results* present robust evidence that solar storms operate as exogenous credit supply shocks in syndicated lending markets.

The Impact of Geomagnetic Storm Intensity (T4)

VARIABLES	(1) OLS	(2) FE (HDFE)	(3) IPW
Storm intensity q $_{t-1}$	0.153**	0.149**	0.473***
	(0.061)	(0.061)	(0.159)
Size_l	-0.048***	-0.045***	-0.037***
	(0.003)	(0.003)	(0.003)
Roa_l	-0.082***	-0.080***	-0.045**
	(0.008)	(0.007)	(0.020)
Rbcr_l	-0.023***	-0.020***	-0.025***
	(0.002)	(0.002)	(0.003)
Lev_l	0.016***	0.016***	0.015***
	(0.000)	(0.000)	(0.001)
Z_score_l	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Dummy NPL	0.788***	0.781***	0.801***
	(0.048)	(0.049)	(0.050)
MaturityYears	0.067***	0.060***	0.048***
	(0.002)	(0.002)	(0.004)
DealAmount	0.010***	0.007***	0.006***
	(0.001)	(0.001)	(0.001)
Roa_b	-0.002	-0.001	-0.000
	(0.004)	(0.004)	(0.004)
Collateral_b	-0.414***	-0.416***	-0.417***
	(0.008)	(0.008)	(0.013)
Altman_Z_Score_b	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Leverage_b	1.022***	1.003***	0.914***
	(0.038)	(0.039)	(0.052)
Size_b	-0.219***	-0.219***	-0.223***
	(0.003)	(0.003)	(0.005)
Tangibility_b	0.034***	0.006	-0.080***
	(0.012)	(0.016)	(0.030)
Constant	2.684***	3.894***	3.890***
	(0.048)	(0.052)	(0.062)
Observations	34,737	34,737	34,737
R-squared	0.323	0.336	0.360
Year FE	YES	YES	YES
Sector FE	YES	YES	YES
ROBUST	YES	YES	YES

The results provide novel empirical evidence that financial markets internalize extreme space weather as a priced risk factor.

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The Impact of Geomagnetic Storm Intensity (T4)

- The findings broaden the scope of environmental finance
- They demonstrating that non-terrestrial, exogenous forces like solar storms can materially influence corporate borrowing conditions in global syndicated loan market.
- We offer *additional insights* into the relationship between solar storms and credit market conditions.
- While the coefficient on storm intensity is statistically significant across all model specifications, its economic magnitude, though modest in isolation, should not be undermined.

The Impact of Geomagnetic Storm Intensity (T4) – Alt Specification

VARIABLES	(1) *DealAmount*	(2) *DealAmount*	(3) *DealAmount*
Storm intensity q_{t-1}	0.252*	0.285**	0.585***
	(0.133)	(0.133)	(0.144)
All_In_Drawn	0.054***	0.064***	-0.277***
	(0.006)	(0.006)	(0.006)
Size_l	-0.054***		-0.019
	(0.007)		(0.044)
Roa_l	-0.042***		-0.079***
	(0.014)		(0.023)
Rbcr_l	-0.021***		-0.079***
	(0.004)		(0.016)
Lev_l	0.004***		0.001
	(0.001)		(0.002)
Z_score_l	0.001		0.018***
	(0.001)		(0.006)
Dummy NPL	0.939***		1.294***
	(0.131)		(0.137)
MaturityYears	-0.124***	-0.122***	-0.140***
	(0.006)	(0.006)	(0.007)
Roa_b	-0.044***	-0.044***	
	(0.008)	(0.008)	
Collateral_b	-0.207***	-0.200***	
	(0.011)	(0.011)	
Altman_Z_Score_b	-0.000***	-0.000***	
	(0.000)	(0.000)	
Leverage_b	0.779***	0.791***	
	(0.033)	(0.033)	
Size_b	0.891***	0.895***	
	(0.008)	(0.008)	
Tangibility_b	-0.780***	-0.781***	
	(0.029)	(0.029)	
Constant	-4.473***	-5.373***	3.033***
	(0.123)	(0.060)	(0.604)
R-squared	0.259	0.258	0.087
Firm Controls	YES	NO	YES
Bank controls	YES	YES	NO
Sector FE	YES	YES	NO
Firm FE	YES	YES	NO
Bank FE	YES	NO	YES
Year FE	YES	YES	YES
Bank FE x Year FE	NO	NO	YES

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The Impact of Geomagnetic Storm Intensity on Syndicate Breadth (T5)

VARIABLES	(1)	(2)	(3)	(4)
	Num_participants	*HHI_lenders*	*Share_foreign_lenders*	*Share_non-bank*
Storm intensity q $_{t-1}$	0.713**	-0.019***	-0.397***	0.032***
	(0.280)	(0.006)	(0.025)	(0.004)
Size_l	-0.192***	0.009***	0.058***	-0.001***
	(0.011)	(0.000)	(0.001)	(0.000)
Roa_l	0.092***	-0.005***	-0.044***	0.001
	(0.025)	(0.001)	(0.003)	(0.001)
Rbcr_l	-0.071***	0.003***	-0.001*	-0.002***
	(0.007)	(0.000)	(0.001)	(0.000)
Lev_l	0.002	0.001***	-0.004***	0.003***
	(0.001)	(0.000)	(0.000)	(0.000)
Z_score_l	-0.004***	-0.000**	0.005***	0.001***
	(0.001)	(0.000)	(0.000)	(0.000)
Dummy NPL	-0.448***	0.107***	-0.198***	-0.029***
	(0.134)	(0.009)	(0.016)	(0.003)
MaturityYears	0.011	-0.008***	0.020***	0.003***
	(0.008)	(0.000)	(0.001)	(0.000)
DealAmount	0.018***	0.002***	0.003***	0.000***
	(0.004)	(0.000)	(0.001)	(0.000)
Roa_b	-0.010***	0.002***	-0.002***	0.001***
	(0.002)	(0.000)	(0.001)	(0.000)
Collateral_b	-0.146***	0.044***	0.065***	-0.013***
	(0.026)	(0.001)	(0.004)	(0.001)
Altman_Z_Score_b	-0.000**	-0.000	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Leverage_b	-0.010	-0.041***	0.246***	0.031***
	(0.068)	(0.003)	(0.010)	(0.002)
Size_b	0.257***	-0.052***	0.101***	-0.006***
	(0.012)	(0.000)	(0.001)	(0.000)
Tangibility_b	-0.033	0.009***	-0.006	-0.004**
	(0.034)	(0.003)	(0.012)	(0.002)
Constant	2.844***	0.440***	-1.160***	0.055***
	(0.183)	(0.008)	(0.024)	(0.004)
Observations	34,737	34,737	34,737	34,737
R-squared	0.277	0.239	0.147	0.089
Year FE	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES
Firm Controls	YES	YES	YES	YES
Robust SE	YES	YES	YES	YES

Higher storm intensity is associated with a significant expansion in syndicate size:

The positive coefficient on l_storm_intensity100 suggests that borrowers actively broaden their lending syndicates to mitigate liquidity risk when systemic conditions deteriorate (Ivashina, 2009).

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The Impact of Geomagnetic Storm Intensity on Syndicate Breadth (T5)

- Greater storm activity is also linked to a significant decline in lender concentration, as reflected in a *lower Herfindahl-Hirschman Index*.

- A more decentralized syndicate structure
  - reduces dependence on dominant lenders and
  - enhances syndicate resilience.

- Moreover, **storm shocks** trigger a notable shift in *syndicate composition*.

- The results confirm that borrowers strategically diversify their syndicate membership
  - to preserve access to credit markets
  - to mitigate risks associated with liquidity shortages and information frictions under systemic uncertainty.

The Impact of Geomagnetic Storm Intensity on Syndicate Leadership and Monitoring (T6)

VARIABLES	(1)	(2)	(3)	(4)
	LeadOwnershipShare	*LeadShare*	*LeadArrangerStrong*	*SoleLead*
Storm intensity q $_{t-1}$	0.208***	-0.072**	0.375***	-0.265*
	(0.064)	(0.032)	(0.046)	(0.151)
Size_l	0.006*	0.004	0.318***	-0.029***
	(0.003)	(0.004)	(0.004)	(0.010)
Roa_l	0.004	0.003	0.025***	0.045**
	(0.006)	(0.005)	(0.008)	(0.021)
Rbcr_l	-0.003**	0.002*	0.043***	0.017***
	(0.001)	(0.001)	(0.002)	(0.005)
Lev_l	-0.001***	0.001***	-0.005***	0.001
	(0.000)	(0.000)	(0.000)	(0.001)
Z_score_l	-0.000	0.000	-0.004***	0.007***
	(0.000)	(0.000)	(0.000)	(0.001)
Dummy NPL	-0.175***	-0.055***	-0.061***	-0.391***
	(0.008)	(0.010)	(0.023)	(0.095)
MaturityYears	-0.002*	-0.003***	-0.012***	-0.064***
	(0.001)	(0.001)	(0.001)	(0.005)
DealAmount	0.008***	0.000*	-0.001	-0.024***
	(0.001)	(0.000)	(0.001)	(0.004)
Roa_b	-0.016***	-0.028**	0.016***	-0.032
	(0.003)	(0.012)	(0.005)	(0.026)
Collateral_b	-0.023***	-0.022*	0.014	-0.175***
	(0.007)	(0.013)	(0.009)	(0.024)
Altman_Z_Score_b	-0.000**	0.002***	0.000	-0.000***
	(0.000)	(0.001)	(0.000)	(0.000)
Leverage_b	-0.048***	-0.009	0.024*	-0.374***
	(0.011)	(0.019)	(0.013)	(0.043)
Size_b	0.017***	-0.036***	-0.014***	-0.238***
	(0.002)	(0.003)	(0.002)	(0.007)
Tangibility_b	0.018	0.011	-0.033*	-0.201***
	(0.015)	(0.015)	(0.018)	(0.039)
Constant	-0.047	0.397***	-3.670***	3.516
	(0.048)	(0.066)	(0.055)	(3.642)
Observations	15,509	3,610	14,762	29,184
R-squared	0.146	0.277	0.450	–
Year FE	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES

Borrowers do increase the total share of loans retained by lead arrangers following systemic shocks.

By retaining a greater share, lead banks enhance their monitoring incentives, aligning their interests more closely with those of the syndicate.

The likelihood of selecting a strong, globally reputable lead arranger also significantly increases.

Borrowers thus prioritize syndicate leaders with superior monitoring capacity and reputational capital

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The Impact of Geomagnetic Storm Intensity on Syndicate Leadership and Monitoring (T6)

- While overall lead commitment rises, the share retained by an individual lead arranger declines.
  - This shift suggests a transition toward shared leadership models, wherein monitoring responsibilities are distributed across multiple reputable institutions

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Heckman Selections Estimates: Loan Estimates and Geomagnetic Storms (T7)

VARIABLES	Two-Step Heckman		MLE Heckman	
	Selection	Outcome	Selection	Outcome
Storm intensity q $_{t-1}$		0.701***		0.662***
		(0.096)		(0.110)
VSW	0.004***		0.004***	
	(0.000)		(0.000)	
High_latitude_exposed	-0.044*		-0.048**	
	(0.023)		(0.023)	
Size_l	0.006	-0.036***	0.005	-0.035***
	(0.005)	(0.004)	(0.005)	(0.004)
Roa_l	-0.026***	-0.094***	-0.025***	-0.098***
	(0.010)	(0.009)	(0.010)	(0.011)
Rbcr_l	0.003	-0.010***	0.003	-0.010***
	(0.003)	(0.002)	(0.003)	(0.002)
Lev_l	-0.001**	0.013***	-0.001*	0.012***
	(0.001)	(0.000)	(0.001)	(0.001)
Z_score_l	0.002***	-0.001**	0.002***	-0.001
	(0.001)	(0.000)	(0.001)	(0.000)
Dummy NPL	0.085	0.685***	0.083	0.693***
	(0.070)	(0.051)	(0.064)	(0.053)
MaturityYears	-0.002	0.058***	-0.002	0.057***
	(0.003)	(0.002)	(0.003)	(0.003)
DealAmount	-0.007***	0.011***	-0.007***	0.010***
	(0.002)	(0.001)	(0.002)	(0.001)
Roa_b	-0.005	-0.004	-0.005**	-0.006
	(0.003)	(0.004)	(0.002)	(0.014)
Collateral_b	-0.018*	-0.503***	-0.016	-0.508***
	(0.011)	(0.009)	(0.011)	(0.011)
Altman_Z_Score_b	0.000***	-0.001***	0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Leverage_b	-0.014	1.079***	-0.014	1.079***
	(0.024)	(0.020)	(0.024)	(0.035)
Size_b	0.014***	-0.240***	0.013***	-0.238***
	(0.004)	(0.003)	(0.003)	(0.004)
Tangibility_b	0.091***	-0.273***	0.090***	-0.259***
	(0.029)	(0.024)	(0.029)	(0.024)
Constant	-5.033***	11.383***	-5.036***	9.670***
	(0.330)	(0.899)	(0.306)	(0.090)
lambda		- -0.595***		
		(0.077)		
athrho				-0.051***
				(0.009)
lnsigma				-0.038***
				(0.007)
Observations	34,737	34,737	34,737	34,737
Year FE	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES

Correcting for *sample selection bias* reinforces our main conclusion:

Exogenous increases in geomagnetic storm intensity significantly elevate syndicated loan spreads.

Our findings are robust to alternative specifications that account for endogenous sample selection.

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DiD Estimation with Cross Industry Heterogeneity (T8)

VARIABLES	(1)	(2)	(3)
Solar_Storm_q $_{t-1}$	0.053***	0.029	0.082***
	(0.020)	(0.022)	(0.026)
Sensitive_FF48	0.079***	0.020	0.017
	(0.007)	(0.018)	(0.018)
Solar_Storm_q $_{t-1}$× Sensitive_FF48	0.109***	0.146***	0.087**
	(0.039)	(0.036)	(0.043)
Size_l	0.051***	-0.030***	-0.029***
	(0.003)	(0.003)	(0.003)
Roa_l	-0.361***	-0.074***	-0.075***
	(0.012)	(0.007)	(0.007)
Rbcr_l	0.051***	-0.008***	-0.008***
	(0.002)	(0.002)	(0.002)
Lev_l	0.011***	0.016***	0.016***
	(0.000)	(0.000)	(0.000)
Z_score_l	0.004***	-0.002***	-0.002***
	(0.000)	(0.000)	(0.000)
Dummy NPL	0.775***	0.673***	0.684***
	(0.051)	(0.050)	(0.050)
MaturityYears	0.049***	0.056***	0.056***
	(0.002)	(0.002)	(0.002)
DealAmount	0.005***	0.009***	0.009***
	(0.001)	(0.001)	(0.001)
Roa_b	-0.005	-0.001	-0.001
	(0.004)	(0.004)	(0.004)
Collateral_b	-0.403***	-0.365***	-0.366***
	(0.008)	(0.008)	(0.008)
Altman_Z_Score_b	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Leverage_b	1.039***	0.967***	0.961***
	(0.039)	(0.037)	(0.040)
Size_b	-0.199***	-0.250***	-0.250***
	(0.003)	(0.003)	(0.003)
Tangibility_b	-0.059***	-0.334***	-0.326***
	(0.014)	(0.024)	(0.024)
Constant	2.169***	4.032***	4.018***
	(0.045)	(0.053)	(0.053)
Observations	34,737	34,737	34,737
R-squared	0.226	0.387	0.387
Year FE	YES	YES	YES

The coefficients imply that firms in sensitive industries face loan spreads approximately 9 to 15 basis points higher than otherwise similar firms during storm quarters.

This DiD framework enables a clean identification of how exogenous physical shocks interact with pre-existing operational vulnerabilities to affect credit terms.

The interaction term isolates the excess premium lenders charge to borrowers in vulnerable industries

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Effect of Geomagnetic Storms on Syndicated Loan Spreads (F1)

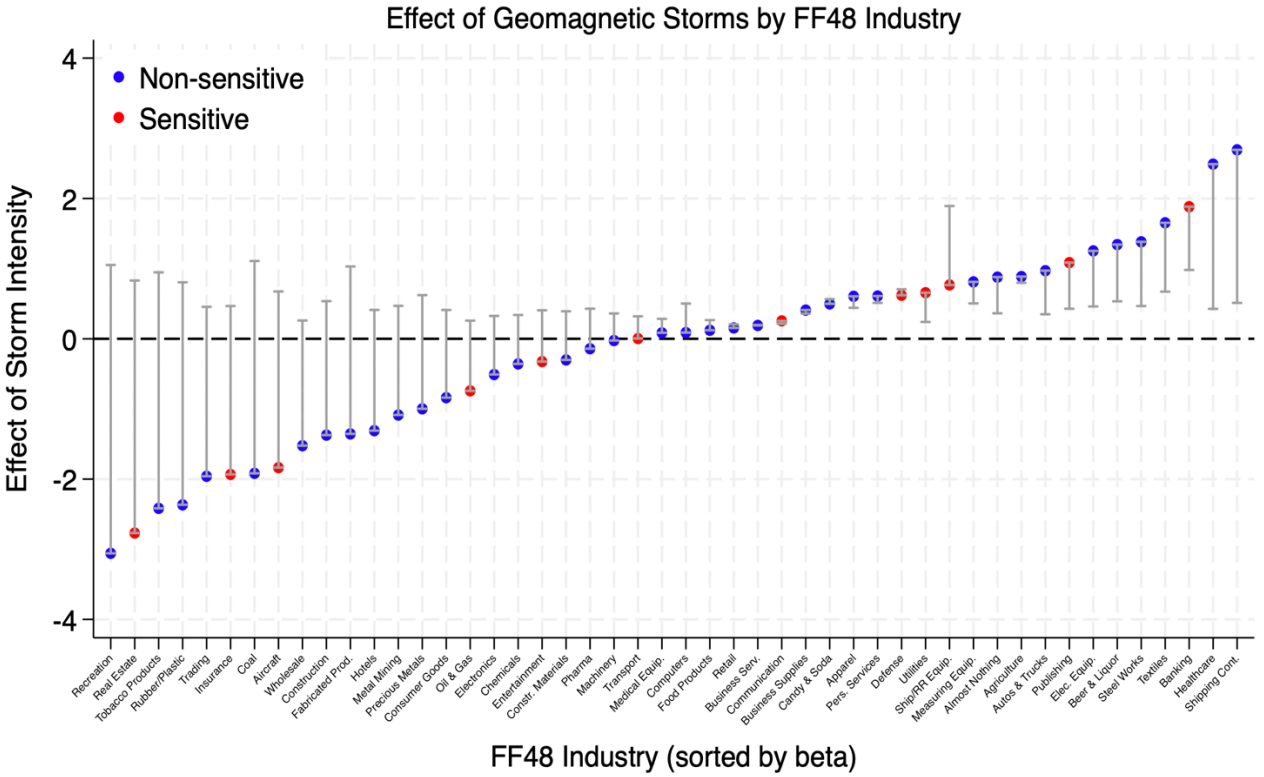

Figure 1 provides a visual representation of the heterogeneity in the estimated sectoral sensitivities (βs) to solar storm activity, *offering a useful mapping of* the cross-sectional impact of solar-induced systemic risk on credit spreads.

This *visual expression* validates the theoretical premise that solar storms do not affect credit markets uniformly, but rather propagate through differentiated channels based on firms' technological and infrastructural dependencies.

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Conclusion

- Loan spreads *increase* *significantly* following episodes of heightened solar activity.

- The effects are more substantial for firms in infrastructure-sensitive industries and in high- latitude regions.

- Solar storms are priced into credit markets, through elevated risk premia

- Evidence indicates that rare, extreme, and largely underexplored shocks, such as solar storms, provoke adjustments.

- Results suggest that banks and syndicate arrangers might underprice the impact of systemic infrastructure disruptions, unless guided by relevant regulatory mandates.

Thank you!

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