Universität Regensburg

IRE|BS
International Real Estate Business School
Universität Regensburg



E-CREDA Research Update
26 May 2026

Do Real Estate Capital Markets Care About Physical Climate Risk?

Jakob Kozak | Hannah Salzberger | Wolfgang Schäfers

Agenda

IRE|BS
International Real Estate Business School
Universität Regensburg

I	**Research Motivation**
II	Literature & Research Questions
III	Data & Methodology
IV	Empirical Results
V	Conclusion

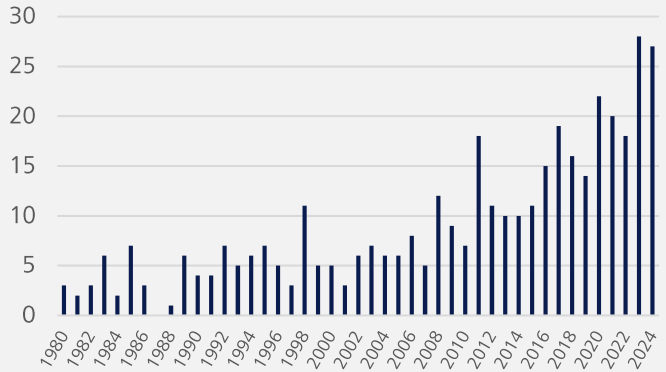
Research Motivation

IRE|BS
International Real Estate Business School
Universität Regensburg

Physical climate risks are a rising priority for REITs' investment strategies

Increase in **frequency** and **severity** of **destructive weather events**[1]

Count of Billion-Dollar Weather Disasters in the U.S.[1]



$183 bn **Cost of Natural Disasters in the U.S. – 2024.**

Current **asset prices do not** adequately **reflect physical climate risk**


Journal of Financial Economics
What do you think about climate finance?
Johannes Stroebel, Jeffrey Wurgler

Stroebel, J., & Wurgler, J. (2021). What do you think about climate finance? *Journal of Financial Economics*

67% of respondents say **climate-related risks** are **not fully priced** in **real estate markets.**

Especially **Real Estate Investors** are **directly** and **indirectly affected** by **physical climate risks**

THE REAL DEAL REAL ESTATE NEWS — 25.09.2024
Climate hazards pose $559B risk to REIT-owned properties

PERE — 30.07.2024
GIC moves climate risk up the real estate priority list

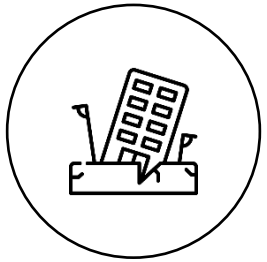
Nareit Real estate working for you — 01.11.2023
Property Level Climate Risk Data Increasingly Important for REITs

[1] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2025).

Research Motivation

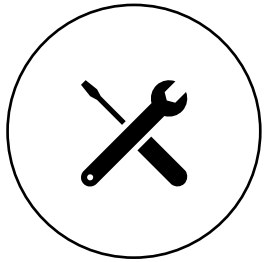
IRE|BS
International Real Estate Business School
Universität Regensburg

Physical climate risks impact real estate portfolios through different channels



Physical Damages to the **Property**

- **Direct loss:** Structural damage to buildings (e.g., roofs, façades, windows).
- **Indirect loss:** Operational disruptions, lost rental income during repair periods.
- **Consequential loss:** Reduced demand (e.g., tourism drop in flood zones), rising insurance premiums.



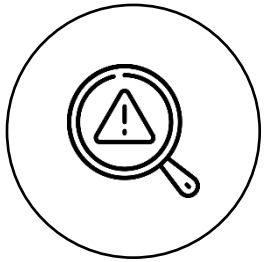
Increased Capital and **Operating Expenditures** (CapEx and OpEx)

Capital Expenses:

- **Investment** in **resilience measures** (e.g., flood doors, backup systems, reinforced infrastructure).
- Need for cooling/heating **infrastructure upgrades.**

Operating Expenses:

- Higher **maintenance costs** to maintain asset value.
- Increased **utility costs.**
- Even under NNN leases, **rising OpEx** can **reduce tenant demand.**



Repricing of REIT Stocks and Bonds

Higher perceived investment risk due to exposure to physical climate risks may be reflected in REIT capital markets through:

- **Higher REIT bond risk premia?**
- **Lower REIT stock returns?**

Agenda

IRE|BS
International Real Estate Business School
Universität Regensburg

I	Research Motivation
II	**Literature & Research Questions**
III	Data & Methodology
IV	Empirical Results
V	Conclusion

Literature & Research Questions

IRE|BS
International Real Estate Business School
Universität Regensburg

Filling the gap in physical climate risk and real estate capital markets research

Hazard	Paper
Hurricane	Contat et al. (2024)
	Kousky et al. (2020)
	Addoum et al. (2024)
	Fisher & Rutledge (2021)
Flood	Yi & Choi (2020)
	Pommeranz & Steininger (2020)
	Fuerst & Warren-Myers (2021)
Wildfire	Götz et al. (2024)
	Issler et al. (2024)
Sea Level Rise	Bernstein et al. (2019)
	Keys & Mulder (2020)
Abnormal Temperature	Cvijanovic & de Minne (2024)
	Feng et al. (2024)
Combined Risk Score	Ling et al. (2024)

Literature focuses on…	Our contribution…
Single hazard types	**Multiple** climate hazards
Housing real estate	**Commercial** real estate (REITs)
Ex-post climate risk data	**Forward-looking** climate risk data
Aggregated exposures (e.g. region-level)	**Asset-level** granular exposure
Little connection to **capital markets**	Analyze **impact** on **REIT capital markets (debt & equity)**

Literature & Research Questions

IRE|BS
International Real Estate Business School
Universität Regensburg

Research Questions



RQ I To what extent **does exposure** to specific **property-level physical climate risks influence REIT bond risk premia**, and do the effects differ across hazard types?

RQ II To what extent **does exposure** to specific **property-level physical climate risks influence REIT equity excess returns**, and do the effects differ across hazard types?

RQ III Are **physical climate risks priced differently** by **institutional** and **retail investors?**

Agenda

IRE|BS
International Real Estate Business School
Universität Regensburg

I	Research Motivation
II	Literature & Research Questions
III	**Data & Methodology**
IV	Empirical Results
V	Conclusion

Data & Methodology

IRE|BS International Real Estate Business School Universität Regensburg

	Bond Market Data	Equity Market Data
Dependent Variable	REIT Bond Risk Premium	REIT Equity Excess Return
Observations	3,131	1,315
REITs	110	103
REIT Properties	18,028	18,017
Period	2021 – 2023	2021 – 2024
Country	USA	USA

Explanatory Variables		
Physical Climate Risk Scores	JUPITER Climate.gov	▪ Flood Risk ▪ Frost Risk ▪ Hurricane Risk ▪ Drought Risk ▪ Wildfire Risk ▪ Realized Hazards (Flood, Frost, Drought, Hurricane, Wildfire)
Controls	S&P Global Market Intelligence FRED ECONOMIC DATA | ST. LOUIS FED	▪ REIT Fundamentals ▪ Equity Market Performance ▪ Macroeconomic Environment ▪ Bond/Equity Market Liquidity

Jupiter Intelligence provides a broader set of metrics and hazard measures. To reduce multicollinearity and preserve the interpretability of hazard-specific estimates, we focus on the most commonly used and real-estate-relevant measures rather than including multiple highly correlated metrics simultaneously.

Data & Methodology

IRE|BS
International Real Estate Business School
Universität Regensburg

Climate Projections

- Projections based on Shared Socioeconomic Pathways (SSP) by the Inter-governmental Panel on Climate Change (IPCC).
- We use the SSP245 ("middle-of-the-road" scenario).
- Risks projected in 5-year intervals up to 2100.

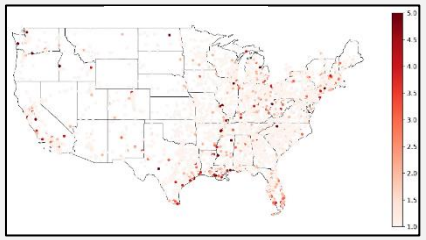
Property-Level Risk Scores

- Physical risk scores computed at the individual property level.
- Hazard-specific measures: Flood, Frost, Hurricane, Drought, Wildfire.
- Example shown below: projected exposure in 2030.

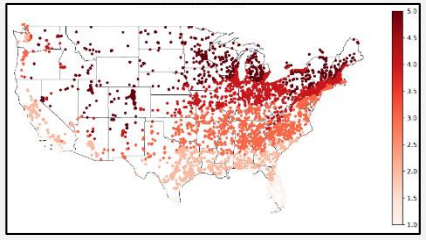
REIT-Level Exposure

- Property-level scores aggregated to REIT level.
- Weighted by each REIT's property portfolio composition.
- Exposure reflects geographic asset distribution.

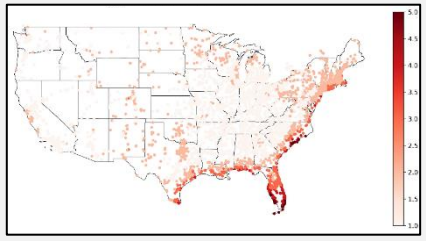
Flood Risk



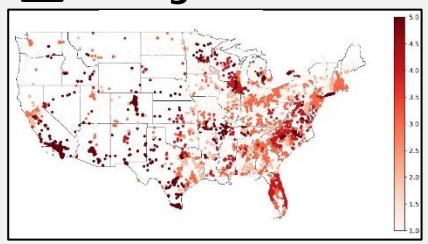
Frost Risk



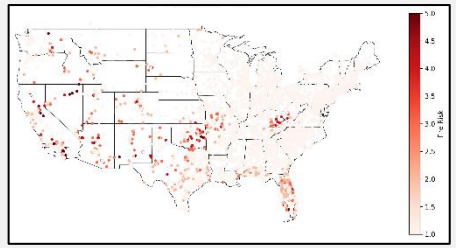
Hurricane Risk



Drought Risk



Wildfire Risk



Methodology

IRE|BS
International Real Estate Business School
Universität Regensburg

Equity and Bond Market Analysis

Panel Regression

- **Estimate** how **hazard-specific climate risks** are associated with **REIT bond spreads** and **REIT stock returns.**
- **Control** for **REIT fundamentals, macro conditions, equity market performance, bond liquidity, bond/time fixed effects.**

REIT bond spreads

$$REIT\ BondRiskSpread_{ijt} = \sum_h \beta_h ClimateRiskScore_{ijt}^{(h)} + \sum_k \beta_k X_{ijt}^{(k)} + \alpha_i + \delta_t + \varepsilon_{ijt}$$

i	Bond
j	REIT
t	Quarter
$ClimateRiskScore^{(h)}$	hazard-specific maturity matched risk score
$X_{ijt}^{(k)}$	firm and market-level covariates
α_i	Bond fixed effects
δ_t	Time fixed effects

REIT stock returns

$$R_{i,t}^{ex} = \sum\nolimits_{h\epsilon H} \sum\nolimits_{k\epsilon K} \beta^{(h,k)} Z_{i,t}^{(h,k)} + \delta' \boldsymbol{C}_{i,t} + \upsilon_i + \tau_t + \varepsilon_{i,t}$$

i	REIT
k	Horizon
t	Quarter
$Z_{i,t}^{(h,k)}$	Hazard- and horizon-specific risk score
$C_{i,t}$	REIT and macroeconomic covariates
υ_i	REIT fixed effects
$\tau_{i,t}$	Time fixed effects

Agenda

IRE|BS
International Real Estate Business School
Universität Regensburg

I	Research Motivation
II	Literature & Research Questions
III	Data & Methodology
IV	**Empirical Results**
V	Conclusion

Empirical Results

IRE|BS International Real Estate Business School Universität Regensburg

I Do physical climate risks affect REIT bond risk premia?

Bond Market (Full Sample)

	Model 1	Model 2	Model 3
Flood Risk	0.0002	0.0053	0.0080*
	(0.0052)	(0.0048)	(0.0047)
Frost Risk	0.0172***	0.0129***	0.0183***
	(0.0043)	(0.0035)	(0.0037)
Hurricane Risk		-0.0020**	
		(0.0009)	
Drought Risk			0.0138***
			(0.0025)
Wildfire Risk	0.0059**		
	(0.0025)		
Cat Bond Insurance RP	0.0031***	0.0039***	0.0028***
	(0.0008)	(0.0008)	(0.0008)
Near Coast	-0.0010**	-0.0007*	-0.0004
	(0.0005)	(0.0004)	(0.0004)
Realized Hazard Events	✓	✓	✓
REIT Fundamentals	✓	✓	✓
REIT Equity Performance	✓	✓	✓
Macroeconomic Factors	✓	✓	✓
Bond Market Liquidity	✓	✓	✓
Bond & Time Fixed Effects	Yes	Yes	Yes
Adj. R^2	0.807	0.810	0.814

Statistically significant in Model 3, indicating that REIT bonds exposed **to higher flood risk** are priced with a higher risk premium.

Statistically significant and positive in all models, suggesting that **frost exposure** contributes to higher bond risk premia.

Small negative and **statistically significant effect** in Model 2. This likely reflects coastal-market fundamentals, insurance, mitigation, and location-specific effects rather than a lower hurricane risk premium.

Positive and significant in Model 3, consistent with higher spreads for drought-exposed REIT bonds.

Positive and significant in Model 1, indicating pricing when wildfire risk is isolated separately.

Empirical Results

IRE|BS
International Real Estate Business School
Universität Regensburg

II Do physical climate risks affect REIT equity excess returns?

Equity Market (Full Sample)

	(1) 5 YRS	(2) 15 YRS	(3) 30 YRS
Flood Risk	-0.1207**	-0.0742	-0.0416
	(0.0602)	(0.0615)	(0.0626)
Frost Risk	0.0768	0.0534	0,0019
	(0.0803)	(0.0820)	(0.0766)
Hurricane Risk	-0.0436	-0.0477	-0.0529
	(0.0591)	(0.0630)	(0.0599)
Drought Risk	-0.1436*	-0.1173*	-0.0746
	(0.0745)	(0.0700)	(0.0569)
Wildfire Risk	-0.0303	-0.0320	-0.0271
	(0.0334)	(0.0324)	(0.0328)
Realized Hazard Events	✓	✓	✓
REIT Fundamentals	✓	✓	✓
REIT Equity Performance	✓	✓	✓
Macroeconomic Factors	✓	✓	✓
Equity Market Liquidity	✓	✓	✓
REIT & Time Fixed Effects	Yes	Yes	Yes
Adj. R^2	0.612	0.610	0.609

- **Equity markets price physical climate risk selectively:** higher exposure is generally associated with lower excess returns, but significance is concentrated in flood and drought risk.
- **Flood risk is negative and significant only at the 5-year horizon**, indicating near-term pricing of flood exposure in REIT equity returns.
- **Drought risk is negative and significant at the 5- and 15-year horizons**, suggesting stronger pricing of short- to medium-term risk.
- **Frost, hurricane, and wildfire risk are insignificant in the full sample**, contrasting with REIT bond markets.
- Overall, **equity investors selectively price acute**, high-impact hazards, **contrasting with broader physical risk pricing** observed in **REIT bond markets.**

Empirical Results

IRE|BS
International Real Estate Business School
Universität Regensburg

III Are physical climate risks priced differently by institutional and retail investors?

Equity Market (Ownership Sample Split)

	Institutional Ownership			Retail Ownership		
	(1) 5 YRS	(2) 15 YRS	(3) 30 YRS	(4) 5 YRS	(5) 15 YRS	(6) 30 YRS
Flood Risk	-0.0578	-0.0163	0.0038	-0.2010*	-0.2810**	-0.3585
	(0.0508)	(0.0395)	(0.0371)	(0.1129)	(0.1369)	(0.2371)
Frost Risk	-0.0133	-0.0313	-0.0724	0.1919	0.1563	0.1553
	(0.0509)	(0.0507)	(0.0522)	(0.1475)	(0.1462)	(0.1450)
Hurricane Risk	0.0378	0.0390	0.0377	-0.1904	-0.2210	-0.3000*
	(0.0233)	(0.0247)	(0.0313)	(0.1944)	(0.1725)	(0.1599)
Drought Risk	-0.0400	-0.0370	-0.0180	-0.2153*	-0.1905*	-0.0989
	(0.0528)	(0.0477)	(0.0346)	(0.1138)	(0.1120)	(0.0972)
Wildfire Risk	-0.0284	-0.0331	-0.0312	-0.0243	-0.0445	-0.0792
	(0.0242)	(0.0211)	(0.0253)	(0.0965)	(0.1003)	(0.1054)
Realized Hazard Events	✓	✓	✓	✓	✓	✓
REIT Fundamentals	✓	✓	✓	✓	✓	✓
REIT Equity Performance	✓	✓	✓	✓	✓	✓
Macroeconomic Factors	✓	✓	✓	✓	✓	✓
REIT & Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.797	0.797	0.796	0.505	0.501	0.499

- **Climate-risk pricing appears almost exclusively in the retail subsample.**
- **Flood and drought exposure are negatively priced** among predominantly retail-owned REITs, especially at 5- and 15-year horizons.
- **Institutional ownership shows no significant residual pricing effects**, consistent with prior incorporation of climate signals.
- **Frost and wildfire remain insignificant** in equity markets, reinforcing the contrast with broader bond-market pricing.

Agenda

IRE|BS
International Real Estate Business School
Universität Regensburg

I	Research Motivation
II	Literature & Research Questions
III	Data & Methodology
IV	Empirical Results
V	**Conclusion**

Conclusion (I/II)

IRE|BS
International Real Estate Business School
Universität Regensburg

Summary & Conclusion

Academic Contributions

- First comprehensive analysis of **forward-looking physical climate risk pricing across** real estate **debt and equity markets.**
- **Distinguishes** pricing effects **across multiple hazard types** and **forecast horizons** using property-level exposures.
- Documents **asymmetric risk pricing**, with broader effects in bond markets and selective pricing in equity markets.
- Shows that **investor sophistication matters**, as institutional investors may have already incorporated climate-risk information, while retail-dominated REITs exhibit stronger residual repricing.

Practical Implications

- **Physical climate risks** represent **material financial risk** factors, particularly for REIT credit markets.
- **Hazard-specific climate analytics are decision-relevant** for investors, lenders, and REIT managers.
- REIT managers may benefit from **risk mitigation and adaptation initiatives** in their **property portfolios**, which could improve financing conditions.
- Findings underscore the **need** for **standardized climate data and disclosure** to improve market efficiency and risk pricing.

Conclusion (II/II)

IRE|BS
International Real Estate Business School
Universität Regensburg

Limitations & Future Research

Limitations

- **Short sample** due to recent availability of forward-looking climate-risk data.
- **REIT location choices are not random** and may reflect endogenous portfolio allocation.
- **Dynamic reallocation may affect exposures**, although no systematic high-to-low risk shift is observed.
- **Scenario uncertainty remains inherent** in forward-looking climate projections.
- **Results capture capital market pricing variation,** not the full economic impact of physical climate risk.

Future Research

- **Extend the sample** as longer climate-risk histories become available.
- **Apply dynamic and causal designs,** e.g. SVAR, IV, or event studies.
- **Distinguish information advantages** from rational inattention or mispricing among investor groups.
- **Compare pricing patterns** across markets, regions, and disclosure regimes.

Contact

Jakob Kozak

Chair of Real Estate Management

Universitätsstraße 31

D-93040 Regensburg

Mobile: +49 173 2032388

Jakob.Kozak@irebs.de

Hannah Salzberger

Chair of Real Estate

Universitätsstraße 31

D-93040 Regensburg

Mobile: +49 176 47392346

Hannah Salzberger@irebs.de

Appendix

Bibliography

Addoum, J. M., Eichholtz, P., Steiner, E., & Yönder, E. (2024). Climate change and commercial real estate: Evidence from Hurricane Sandy. *Real Estate Economics, 52*(3), 687–713. https://doi.org/10.1111/1540-6229.12435

Bernstein, A., Gustafson, M. T., & Lewis, R. (2019). Disaster on the horizon: The price effect of sea level rise. *Journal of Financial Economics, 134(2)*, 253–272. https://doi.org/10.1016/j.jfineco.2019.03.013

Carrão, H., G. Naumann, and P. Barbosa (2018). Global projections of drought hazard in a warming climate: a prime for disaster risk management. *Climate Dynamics 50(5)*,2137–2155. https://doi.org/10.1007/s00382-017-3740-8

Contat, J. C., Doerner, W. M., Renner, R. N., & Rogers, M. J. (2024). Measuring Price Effects from Disasters Using Public Data: A Case Study of Hurricane Ian. *Journal of Real Estate Research, 0*(0), 1–48. https://doi.org/10.1080/08965803.2024.2391213

Cvijanovic, D., & Van de Minne, A. (2023). *Does Climate Change Affect Investment Performance? Evidence From Commercial Real Estate* (SSRN Scholarly Paper 3960805). Social Science Research Network. https://doi.org/10.2139/ssrn.3960805

Duan, K., G. Sun, P. V. Caldwell, S. G. McNulty, and Y. Zhang (2018). Implications of Upstream Flow Availability for Watershed Surface Water Supply across the Conterminous United States. *JAWRA Journal of the American Water Resources Association, 54*(3),694–707. https://doi.org/10.1111/1752-1688.12644

Fisher, J. D., & Rutledge, S. R. (2021). The impact of Hurricanes on the value of commercial real estate. *Business Economics, 56*(3), 129–145. https://doi.org/10.1057/s11369-021-00212-9

Fuerst, F., & Warren-Myers, G. (2021). Pricing climate risk: Are flooding and sea level rise risk capitalised in Australian residential property? *Climate Risk Management, 34*, 100361. https://doi.org/10.1016/j.crm.2021.100361

Götz, L., Mager, F., & Zietz, J. (2024). The Effect of Wildfires on Mortgage Pricing: Evidence from Portugal. *The Journal of Real Estate Finance and Economics.* https://doi.org/10.1007/s11146-024-09982-3

Issler, P., Stanton, R., Vergara-Alert, C., & Wallace, N. (2024). *Housing and Mortgage Markets with Climate Risk: Evidence from California Wildfires.* [Working Paper]. Social Science Research Network. http://dx.doi.org/10.2139/ssrn.3511843

Keys, B. J., & Mulder, P. (2020). *Neglected No More: Housing Markets, Mortgage Lending, and Sea Level Rise* [Working Paper 27930]. National Bureau of Economic Research. https://doi.org/10.3386/w27930

Kousky, C., Palim, M., & Pan, Y. (2020). Flood Damage and Mortgage Credit Risk: A Case Study of Hurricane Harvey. *Journal of Housing Research, 29*(sup1), S86–S120. https://doi.org/10.1080/10527001.2020.1840131

Ling, D. C., Robinson, S., Sanderford, A. R., & Wang, C. (2024). Climate change and commercial property markets. *Journal of Regional Science, 64*(4), 1066–1098. https://doi.org/10.1111/jors.12717

Mueller, J., Loomis, J., & González-Cabán, A. (2009). Do Repeated Wildfires Change Homebuyers' Demand for Homes in High-Risk Areas? A Hedonic Analysis of the Short and Long-Term Effects of Repeated Wildfires on House Prices in Southern California. *The Journal of Real Estate Finance and Economics, 38*(2), 155–172. https://doi.org/10.1007/s11146-007-9083-1

O'Neill, B. C., Tebaldi, C., van Vuuren, D. P., Eyring, V., Friedlingstein, P., Hurtt, G., Knutti, R., Kriegler, E., Lamarque, J.-F., Lowe, J., Meehl, G. A., Moss, R., Riahi, K., & Sanderson, B. M. (2016). The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6. *Geoscientific Model Development, 9*(9), 3461–3482. https://doi.org/10.5194/gmd-9-3461-2016

Pommeranz, C., & Steininger, B. I. (2020). Spatial Spillovers in the Pricing of Flood Risk: Insights from the Housing Market. *Journal of Housing Research, 29*(sup1), S54–S85. https://doi.org/10.1080/10527001.2020.1839336

Sanders, B. F., J. E. Schubert, D. T. Kahl, K. J. Mach, D. Brady, A. AghaKouchak, F. Forman, R. A. Matthew, N. Ulibarri, and S. J. Davis (2023). Large and in-equitable flood risks in Los Angeles, California. *Nature Sustainability, 6*(1), 47–57.https://doi.org/10.1038/s41893-022-00977-7

Touma, D., M. Ashfaq, M. A. Nayak, S.-C. Kao, and N. S. Diffenbaugh (2015). A multi-model and multi-index evaluation of drought characteristics in the 21st century. *Journal of Hydrology 526*, 196–207. https://doi.org/10.1016/j.jhydrol.2014.12.011

Yi, D., & Choi, H. (2020). Housing Market Response to New Flood Risk Information and the Impact on Poor Tenant. *The Journal of Real Estate Finance and Economics, 61*(1), 55–79. https://doi.org/10.1007/s11146-019-09704-0

Data & Methodology

IRE|BS International Real Estate Business School Universität Regensburg

Bond Market Data

Variable Group	Source	Variable Name(s)
Dependent Variable	FINRA	▪ REIT Bond Risk Premium
Physical Climate Risk Scores	JUPITER	▪ Flood Risk ▪ Frost Risk ▪ Hurricane Risk ▪ Drought Risk ▪ Wildfire Risk
REIT Fundamentals	S&P Global Market Intelligence	▪ Return on Assets ▪ Leverage ▪ FFO ▪ HHI
REIT Equity Performance	S&P Global Market Intelligence	▪ Market Capitalization ▪ Market to Book ▪ Dividends ▪ Equity Return
Equity Market	FRED Economic Data | St. Louis Fed	▪ S&P 500 Return
Macroeconomic Environment	FRED Economic Data | St. Louis Fed	▪ Unemployment in MSAs ▪ GDP in MSAs ▪ Term Spread
Bond Market Liquidity	FINRA	▪ Zero Trading Days ▪ Bid-Ask Spread

Equity Market Data

Variable Group	Source	Variable Name(s)
Dependent Variable	S&P Global Market Intelligence	▪ REIT Equity Excess Return
Physical Climate Risk Scores	JUPITER	▪ Flood Risk ▪ Frost Risk ▪ Hurricane Risk ▪ Drought Risk ▪ Wildfire Risk
REIT Fundamentals	S&P Global Market Intelligence	▪ Return on Assets ▪ Leverage ▪ FFO ▪ HHI
REIT Equity Performance	S&P Global Market Intelligence	▪ Market Capitalization ▪ Dividends
Realized Hazard Events	Climate.gov	▪ Realized Flood Count ▪ Realized Frost Count ▪ Realized Hurricane Count ▪ Realized Drought Count ▪ Realized Wildfire Count
Macroeconomic Environment	FRED Economic Data | St. Louis Fed	▪ Risk Free Interest Rate ▪ GDP in MSAs
Equity Market Liquidity	S&P Global Market Intelligence	▪ Trading Volume

Data – Description of Physical Climate Risk Data

IRE|BS
International Real Estate Business School
Universität Regensburg

	Description
General Information	Jupiter's ClimateScore Global quantifies physical climate risk anywhere in the world. In our study we use the five perils described below for REIT properties in the United States. Peril metrics (e.g., wind speed, flood depth) are physical quantities from Global Climate Models (GCM)-driven modeling. Since different perils are expressed in heterogeneous units that are not directly comparable, these bands are subsequently mapped to generic risk tiers with qualitative labels: lowest, low, medium, high, and highest. This tier system provides a unit-agnostic, harmonized risk scale that facilitates comparison of exposure across different peril types.
Acute Risk: Flood	The flood peril metric used in this study is the projected flood depth for a 100-year return period. The flood model combines coastal flood, fluvial (river) flood, and pluvial (rainwater) floods; results are reported as a combined flood depth (maximum across types). Tiers/bands follow Sanders et al. (2023).
Acute Risk: Hurricane	The acute wind-speed metric used in this study represents the expected 1-minute sustained wind speed (km/h) for 100-year events, modeling tropical cyclones and large extratropical storms. Tiers/bands follow the Saffir–Simpson Hurricane Wind Scale classification.
Acute Risk: Wildfire	The wildfire metric estimates annual probability of a catastrophic wildfire affecting an asset, trained on high-resolution geospatial predictors. Baseline (1995) probabilities are scaled by changes in air temperature and humidity called vapor pressure deficit (VPD). Downscaling from ERA5 to 90 m incorporates additional geospatial features. Tiers/bands are based on quantiles across 430,000 global locations.
Chronic Risk: Frost	Cold peril metrics characterize extreme low-temperature exposure. Here, "cold days" are days per year with air temperature ≤ 0 °C / ≤ 32 °F. Tiers/bands are based on the distribution of cold days in populated regions globally.
Chronic Risk: Drought	Water stress is water demand divided by available water supply (WRI Aqueduct 4.0), delivered on the 90 m CSG grid. Demand projections reflect CMIP6 forcing and sectoral changes (domestic, industrial, livestock). Stress is computed over watershed boundaries (accounts for routing/flow accumulation). Tiers/bands are based on the distribution of water stress in populated regions and the work from Duan et al. (2018), Touma et al. (2015) and Carráo et al. (2018).
Climate Scenario	This study uses the SSP2 - RCP4.5 climate scenario. SSP2- RCP4.5, the "Middle of the road" or medium pathway extrapolates the past and current global development into the future. Emissions growth continues to increase then begins leveling out by 2050 and declining after. In the IPCC's 6th Assessment Report, this scenario was deemed to be the "most likely" scenario. This scenario is coupled with RCP 4.5 radiative forcing, resulting in likely global warming of 2.1–3.5 °C in 2100 compared to a 1986–2005 baseline average.
Time Horizons	2025–2100 in 5-year intervals.

Data & Methodology

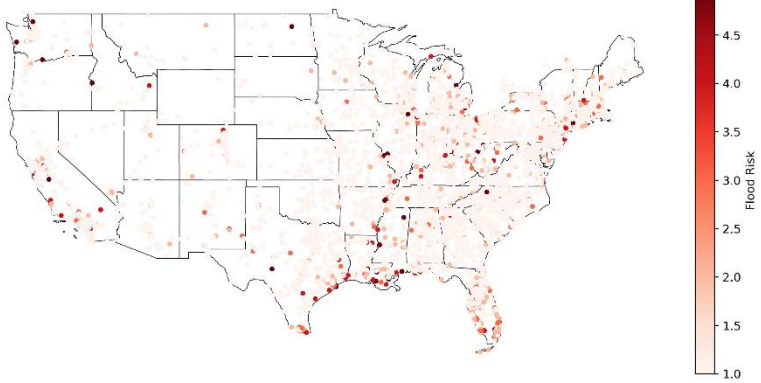
IRE|BS
International Real Estate Business School
Universität Regensburg

Physical climate risk maps for the year 2030

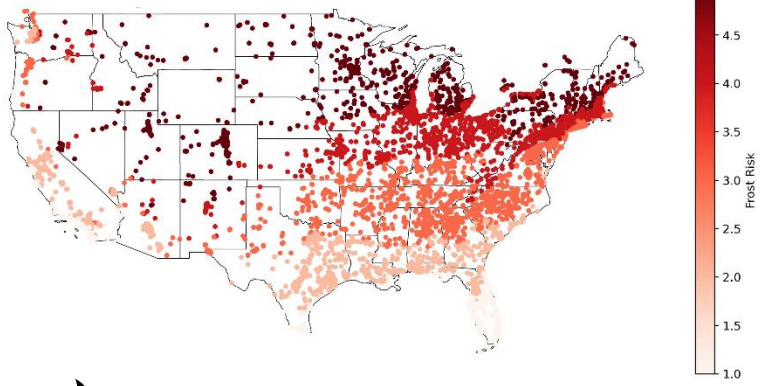
Physical Climate Risk Time Horizons

- **Scores** represent **expected risks** projected into the **future up to the year 2100**
- Risks are **assessed** in **5-year intervals** (e.g., 2030, 2035, 2040 etc.)

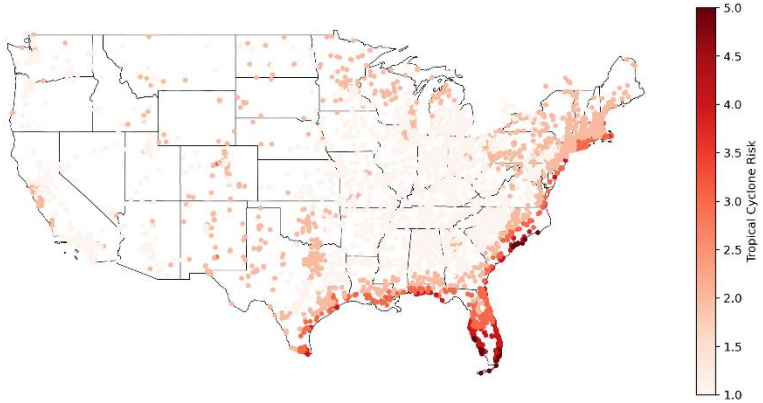
Flood Risk



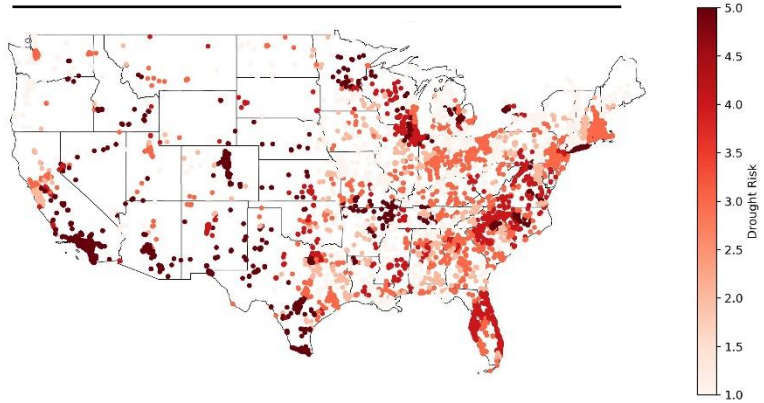
Frost Risk



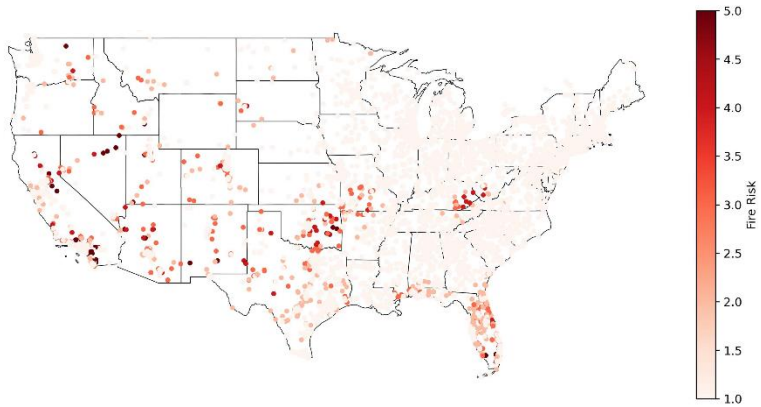
Hurricane Risk



Drought Risk



Wildfire Risk



Data – Variable Description

IRE|BS
International Real Estate Business School
Universität Regensburg

Category	Abbreviation	Variable	Description
Bond Market Outcome	BRP	Bond Risk Premium	Difference between the corporate bond yield and the corresponding risk-free benchmark yield
Equity Market Outcome	EXRET	Excess Return	REIT stock return in excess of the risk-free rate
Forward-Looking Physical Climate Risk	FLOOD	Flood Risk	Forward-looking flood risk score for REIT properties
	FROST	Frost Risk	Forward-looking frost risk score for REIT properties
	HURR	Hurricane Risk	Forward-looking hurricane risk score for REIT properties
	DROUGHT	Drought Risk	Forward-looking drought risk score for REIT properties
	FIRE	Wildfire Risk	Forward-looking wildfire risk score for REIT properties
Realized Hazard Events	RFLOOD	Realized Flood Events	Number of events classified as Flood or Flash Flood in the NOAA Storm Events Database affecting REIT properties
	RFROST	Realized Frost Events	Number of events classified as Frost/Freeze in the NOAA Storm Events Database affecting REIT properties
	RHURR	Realized Hurricane Events	Number of events classified as Hurricane (Typhoon) or Tropical Storm in the NOAA Storm Events Database affecting REIT properties
	RDROUGHT	Realized Drought Events	Number of events classified as Drought in the NOAA Storm Events Database affecting REIT properties
	RFIRE	Realized Wildfire Events	Number of events classified as Wildfire in the NOAA Storm Events Database affecting REIT properties
Insurance and Geographic Exposure	CATBOND	Cat Bond Insurance Risk Premium	Insurance-market risk premium derived from catastrophe bond pricing
	COAST	Near Coast	Share of REIT properties located near the coast
Macroeconomic Controls	TERM	Term Spread	Difference between long-term and short-term interest rates
	UNEMP	MSA Unemployment Rate	Unemployment rate in the metropolitan statistical area of the REIT property
	GDP	MSA GDP	Gross domestic product of the metropolitan statistical area of the REIT property
	SP500	S&P 500 Return	Return or index performance of the S&P 500 market portfolio
Firm-Level Controls	HHI	HHI	Portfolio concentration measure based on the Herfindahl-Hirschman Index
	MCAP	Market Capitalization	Market value of the REIT's equity
	FFO	Funds From Operations	REIT operating performance measure based on funds from operations
	LEV	Leverage	Ratio of debt to total assets or capital structure measure
	EQRET	Equity Return	Total return of the REIT's equity
	DIV	Dividends	Dividends paid by the REIT
	MTB	Market to Book	Ratio of market value to book value
	ROA	Return on Assets	Ratio of net income or operating return to total assets
Equity Risk Factors	RF	Risk-Free Interest Rate	Risk-free interest rate used as benchmark return
	MKT	Market Risk Factor Beta	Excess return of the market over the risk-free rate
	SMB	Size Factor SMB	Excess return of small-cap stocks over large-cap stocks
	HML	Value Factor HML	Excess return of value stocks over growth stocks
	RMW	Profitability Factor RMW	Excess return of profitable firms over less profitable firms
	CMA	Investment Factor CMA	Excess return of conservative investment firms over aggressive investment firms
Bond Market Liquidity	FZEROT	Firm Zero Trading Days	Percentage of days in a month with no bond trading
	BIDASK	Bid-Ask Spread	Monthly mean difference between bid and ask prices
Equity Market Liquidity	VOL	Volume	Daily traded volume of a REIT's stock

Data – Summary Statistics Bond Market

IRE|BS International Real Estate Business School Universität Regensburg

Variable	Unit	Mean	Median	SD	Min	Max
Bond Risk Premium	Decimal	0.012	0.011	0.011	-0.032	0.053
Flood Risk	Index	0.242	0.174	0.221	0.000	1.513
Frost Risk	Index	1.548	1.629	0.586	0.000	3.000
Hurricane Risk	Index	0.669	0.727	0.389	0.000	4.031
Drought Risk	Index	2.226	2.171	0.463	0.000	4.022
Fire Risk	Index	0.107	0.108	0.095	0.000	0.460
Realized Flood Events	Count	13,058	7,313	16,848	0	151,633
Realized Frost Events	Count	2,372	649	4,855	0	44,866
Realized Drought Events	Count	9,115	5,654	10,934	0	57,364
Realized Hurricane Events	Count	885	0	2,499	0	21,013
Realized Wildfire Events	Count	779	393	1,056	0	8,181
Cat Bond Insurance Risk Premium	Percentage	2.455	2.625	2.293	0.018	5.431
Near Coast	Percentage	21.682	22.140	17.145	0.000	100.000
Term Spread	Decimal	-0.021	-0.022	0.035	-0.066	0.015
MSA Unemployment Rate	Decimal	0.041	0.036	0.009	0.035	0.061
MSA GDP	USD	21,878.647	21,851.130	456.361	20,990.540	22,679.260
HHI	Integer	-0.146	-0.081	0.195	-1.000	-0.263
S&P 500 Return	Index	4,229.074	4,345.370	295.658	3,850.520	4,685.050
Market Capitalization	Mio. USD (log)	23.300	23.393	0.959	20.892	25.533
FFO	USD	5.164	3.967	3.470	0.500	14.900
Leverage	Decimal	0.479	0.478	0.123	0.286	0.768
Equity Return	Decimal	0.012	0.017	0.136	-0.345	0.350
Dividends	USD	3.212	2.474	2.213	0.040	9.020
Market to Book	Integer	1.992	1.758	1.083	0.410	6.155
Return on Assets	Decimal	0.008	0.008	0.007	-0.012	0.032
Bid Ask Spread	Decimal	0.008	0.005	0.009	0.001	0.051
Zero Trading Days	Decimal	0.310	0.300	0.048	0.258	0.533

Data – Summary Statistics Equity Market

IRE|BS
International Real Estate Business School
Universität Regensburg

Variable	Unit	Mean	Median	SD	Min	Max
Excess Return	Decimal	-0.022	-0.019	0.179	-0.962	1.067
Flood Risk Current	Index	1.226	1.169	0.238	1.000	2.500
Flood Risk 5 YRS	Index	1.229	1.174	0.239	1.000	2.500
Flood Risk 15 YRS	Index	1.243	1.177	0.286	1.000	3.000
Flood Risk 30 YRS	Index	1.261	1.182	0.317	1.000	3.000
Frost Risk Current	Index	2.884	2.972	0.813	1.000	5.000
Frost Risk 5 YRS	Index	2.831	2.926	0.778	1.000	4.923
Frost Risk 15 YRS	Index	2.731	2.900	0.736	1.000	4.923
Frost Risk 30 YRS	Index	2.642	2.826	0.733	1.000	4.923
Hurricane Risk Current	Index	1.636	1.577	0.468	1.000	5.000
Hurricane Risk 5 YRS	Index	1.641	1.591	0.469	1.000	5.000
Hurricane Risk 15 YRS	Index	1.652	1.609	0.468	1.000	5.000
Hurricane Risk 30 YRS	Index	1.678	1.642	0.462	1.000	5.000
Drought Risk Current	Index	3.092	3.095	0.767	1.000	5.000
Drought Risk 5 YRS	Index	3.097	3.105	0.766	1.000	5.000
Drought Risk 15 YRS	Index	3.092	3.098	0.759	1.000	5.000
Drought Risk 30 YRS	Index	3.040	3.043	0.763	1.000	5.000
Wildfire Risk Current	Index	1.098	1.059	0.135	1.000	2.000
Wildfire Risk 5 YRS	Index	1.099	1.059	0.135	1.000	2.000
Wildfire Risk 15 YRS	Index	1.102	1.063	0.136	1.000	2.000
Wildfire Risk 30 YRS	Index	1.104	1.069	0.138	1.000	2.000
Realized Flood Events	Count	128	13	195	0	1,139
Realized Frost Events	Count	25	0	55	0	322
Realized Drought Events	Count	72	0	127	0	587
Realized Hurricane Events	Count	12	0	32	0	197
Realized Wildfire Events	Count	8	0	14	0	66
Cat Bond Insurance Risk Premium	Percentage	3.088	4.496	2.306	0.018	5.431
Near Coast	Decimal	0.217	0.108	0.277	0.000	1.000
Return on Assets	Decimal	0.017	0.019	0.078	-1.291	1.258
Leverage	Decimal	0.416	0.382	0.179	0.031	0.973
FFO	USD	132,222	59,893	213,156	-779,959	1,896,639
HHI	Integer	-0.245	-0.127	0.298	-1.000	-0.008
Market Capitalization	Mio USD (log)	8,758	2,901	15,586	2	124,557
Dividends	USD	-90,298	-33,501	156,370	-2,718,800	512
Risk-Free Interest Rate	Decimal	0.032	0.044	0.023	0.000	0.055
Market Risk Factor Beta	Percentage	0.942	0.986	0.632	-6.963	3.023
Size Factor SMB	Percentage	1.084	1.098	0.840	-2.172	5.127
Value Factor HML	Percentage	0.205	0.262	0.817	-5.603	2.415
Profitability Factor RMW	Percentage	0.688	0.679	0.781	-2.279	4.746
Investment Factor CMA	Percentage	0.933	0.781	1.353	-2.794	10.180
MSA GDP	USD	1,212,151	1,064,405	645,702	81,276	3,392,762
Trading Volume	USD	1,289,796	845,081	1,761,494	8	24,134,000

Methodology – SSP Climate Scenarios

IRE|BS International Real Estate Business School Universität Regensburg

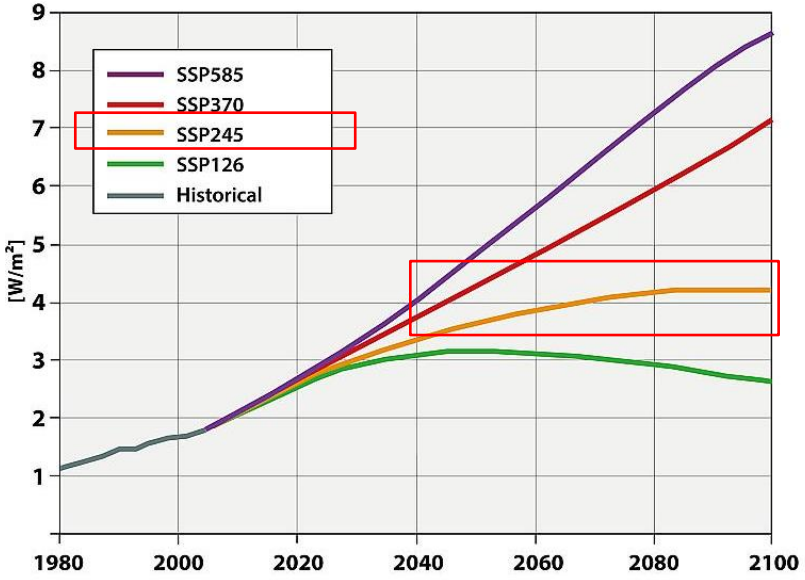
Physical climate risk projections are based on moderate global warming scenario

About the Shared Economic Pathways (SSP)

- The forward-looking climate risk projections we use are based on climate scenarios following the Shared Economic Pathways (SSP-Scenarios)
- SSP-Scenarios are coordinated by the Intergovernmental Panel on Climate Change (IPCC)
- SSP predicts future social, economic, and technological trends which have an impact on climate change
- We follow the SSP245-Scenario, the so called "Middle of the road"-Scenario, where predicted trends do not shift markedly from historical patterns
- Under SSP245 the predicted global warming exceeds 2 °C

Graphical Representation of the SSP-Scenarios

Total anthropogenic radiative forcing[1]



Methodology – Aggregating Climate Risk Scores

IRE|BS International Real Estate Business School Universität Regensburg

Aggregating physical climate risk at the property level to REIT-level

1 Aggregate Climate Risk Score on REIT level

- Compute REIT-level physical climate risk per hazard type (e.g., flood, drought) by averaging projected hazard exposures across all owned properties.
- Scores are available for 2025 to 2100, in 5-year intervals.

$$\bar{R}_{jht} = \frac{1}{N_{jht}} \sum_{t} R_{jht}$$

2 Center by REIT-Property Type Mean

- Adjust each REIT's score relative to the median of its property type.
- Enables within-type comparisons and controls for structural differences in property-type-specific baseline risk exposure.

$$D_{j,t}^{(h,k)} = \bar{R}_{j,t}^{(h,k)} - \widetilde{R_{c(j,t),t}^{(h,k)}}$$

$$\text{with } \widetilde{R_{c,t}^{(h,k)}} = median_{\iota:c(\iota,t)=c} \bar{R}_{\iota t}^{(h,k)}$$

3 Rescale within Property Type

- Centered scores are rescaled to non-negative values within each property type and quarter.
- Produces standardized, comparable risk scores across REITs.

$$\widehat{R_{jt}^{(h,k)}} = \frac{D_{jt}^{(h,k)} - min_{\iota:c(\iota,t)=c(\iota,t)} D_{\iota t}^{(h,k)}}{max_{\iota:c(\iota,t)=c(j,t)} D_{\iota t}^{(h,k)} - min_{\iota:c(\iota.t)=c(j,t)} D_{\iota t}^{(h,k)}}$$

R = Raw Climate Risk Score, j = REIT, h = hazard, t = time, a = property type

Methodology – Climate Score Validation

IRE|BS
International Real Estate Business School
Universität Regensburg

Physical Climate Scores Highly Correlated with Scores from Large Reinsurance Company

Risk	Scenario	Horizon pairs	Mean Pearson	Min Pearson	Max Pearson	Mean Spearman	Mean Kendall
FLOOD (Flood Risk)	SSP2–4.5	4.000	0.895	0.888	0.905	0.898	0.753
FLOOD (Flood Risk)	SSP5–8.5	3.000	0.999	0.997	1.000	0.992	0.955
HURRICANE (Hurricane Risk)	SSP2–4.5	4.000	0.755	0.689	0.840	0.930	0.881
HURRICANE (Hurricane Risk)	SSP5–8.5	3.000	0.985	0.958	1.000	0.971	0.934
DROUGHT (Drought Risk)	SSP2–4.5	5.000	0.944	0.941	0.949	0.930	0.791
DROUGHT (Drought Risk)	SSP5–8.5	4.000	0.962	0.933	0.982	0.956	0.857
FIRE (Wildfire Risk)	SSP2–4.5	5.000	0.970	0.946	0.979	0.965	0.899
FIRE (Wildfire Risk)	SSP5–8.5	4.000	0.983	0.956	0.999	0.979	0.920

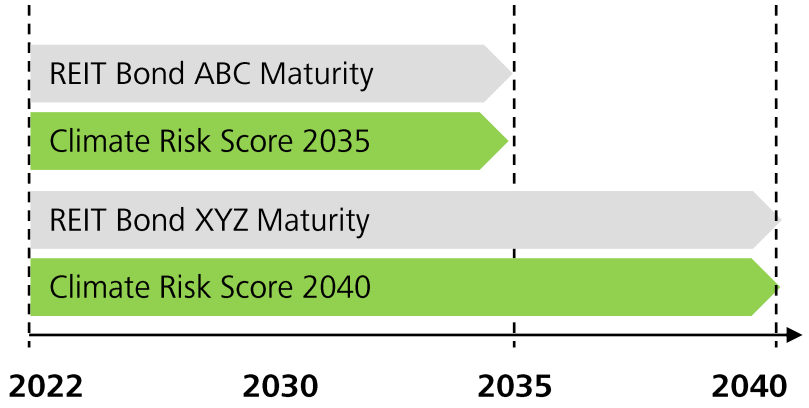
Methodology – Bond Market Analysis

IRE|BS International Real Estate Business School Universität Regensburg

Model for the Bond Market Analysis: Panel Regression

Step 1: Match Climate Risk Score to Bond Maturity

- Each **bond** is **linked** to the REIT's standardized **climate risk score closest** to its **maturity year.**
- This **links physical climate risk** to **bond-specific maturity.**



Step 2: Model Objective and Setup

- **Estimate** how **hazard-specific climate risk** affects REIT bond spreads.
- **Control** for **REIT fundamentals**, **macro conditions**, **equity market performance**, **bond liquidity** and **bond/time fixed effects.**

$$REIT\ BondRiskSpread_{ijt} = \sum_{h} \beta_h ClimateRiskScore_{ijt}^{(h)} + \sum_{k} \beta_k X_{ijt}^{(k)} + \alpha_i + \delta_t + \varepsilon_{ijt}$$

i	Bond
j	REIT
t	Quarter
$ClimateRiskScore^{(h)}$	hazard-specific maturity matched risk score
$X_{ijt}^{(k)}$	firm and market-level covariates
α_i	Bond fixed effects
δ_t	Time fixed effects