Nailing Down Volatile Temperatures

Examining their Effects on Asset Prices

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Motivation

The 'what' in measuring climate physical exposure

- Large companies and financial firms in the UK must disclose climate information following Task Force on Climate-Related Financial Disclosures (TCFD) guidelines.
- EU is working on its Corporate Sustainability Reporting Directive.
- SEC voted to issue proposals for mandatory climate risk reporting.
- Unlike direct and indirect emissions (scope 1 and 2), no specific metric for physical climate exposure.
- This is problematic: disclosure of physical climate exposure needs to be standardised, mandatory and regulated in the same way as emission reporting to ensure it is consistent, transparent, and verified.

"Why investors need not worry about climate risk"

Figure: Stuart Kirk at Financial Times Moral Money, May 2022

- Frustration with climate regulation is quietly shared by many in the finance industry.
- Many think of climate change (CC) as another fashionable but financially irrelevant concern.
- Objection rooted in the inability to isolate the effect of physical phenomena related to CC.
- Identification problem $\rightarrow$ isolate impact of CC.

The most studied phenomenon: Temperature anomalies (TA)

Growing *climate economics* literature relates changes (deviations and variability) in TA to economic aggregate:

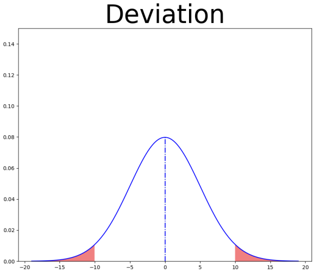
- Agriculture: crop-yields (Wheeler et al., 2000, Ceglar et al., 2016)
- Human health and mortality (Zanobetti et al., 2011)
- Economic growth (Donadelli et al., 2017, Kotz et al., 2021)
- Economic beliefs (Makridis and Schloetzer (2021))

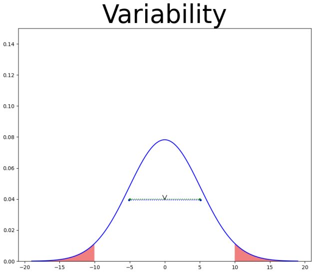
Climate finance examines effect of changes in TA on firm performance

- Average effects on sales and productivity close to zero, Addoum et al., 2020
- Weak stock return sensitivity, among o. Kumar et al (2019)
- Extremes reduce firms' revenues and operating income, Pankratz and Schiller, 2021

Temperature anomalies characteristics

- Changes in *temperature anomalies* described by:
  1. shift in the whole distribution of temperature anomalies,
  2. changes in the shape of the distribution of temperature anomalies.

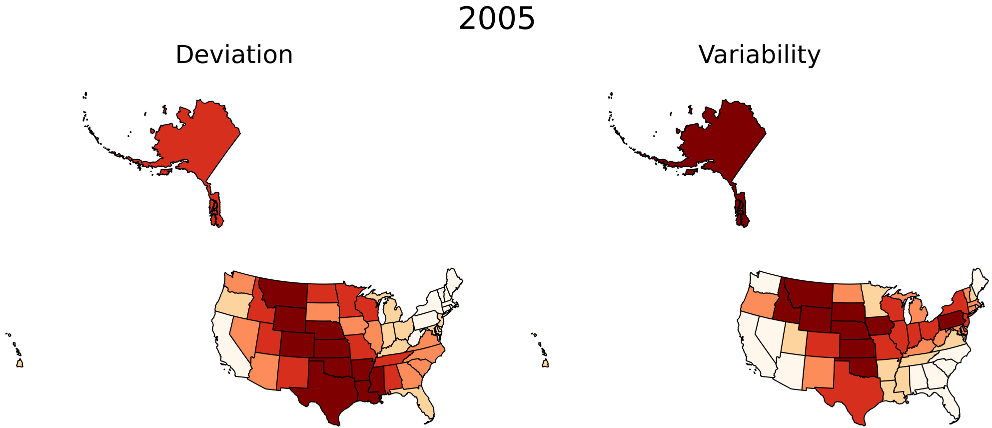




- We examine which 'metric' allows to isolate the impact of temperature.

Constructing our metrics of temperature anomalies in the U.S.

- More granular data allow better empirical assessment of the implications of temperature anomalies: Gridded 1-degree latitude by 1-degree longitude daily temperature data



Results

Research steps to nail down effect of temperature on stocks 1/3

- **Effect:** estimating temperature exposure on U.S. stock markets (Russel 3000) via asset pricing factor analysis:
  - *Average* firm in Russel 3000 unaffected (Addoum et al (2020) and Dell et al (2012)).
  - While only Utilities exposed to *TD*, Energy and Consumer sectors are negatively impacted by *TD-VAR*.
  - Consistent with labor productivity (Graff Zivin and Neidell (2014)) and consumer demand channels (Starr (2000)).
  - Contribution: *TD-VAR* allows to isolate the impact of temperature.

Research steps to nail down effect of temperature on stocks 2/3

- **Reaction:** examine investors' reaction to state-level heterogeneity in temperature anomalies:
  - Sort states into quintiles based on their *TD* and *TD-VAR* exposure.
  - Form long–short spread portfolios: going long on firms in less-exposed states and short on firms in the most-exposed states.
  - Results underscore a considerably larger reaction to local deviations in *TD-VAR* than *TD*.
  - Investors can reduce their exposure to temperature by considering local variability in temperature anomalies.
  - Contribution: *TD-VAR* is a financially relevant metrics.

Research steps to nail down effect of temperature on stocks 3/3

- **Attribution:** disentangle ‘material’ impact of temperature from the effect of attention to temperature-related events
  - Compute attention-adjusted reaction to temperature anomalies using
    - Engle et al., 2020 climate change news;
    - Google Search Volume Indexes for State-specific representations of climate attention;
    - Sautner et al., 2020 exposure measure based on earnings calls (EC).
  - Effect of *TD-VAR* goes beyond attention.
  - Currently looking into Form 10-K to better capture 'material' exposure and mitigate problem of analysts on EC having to be attentive to climate change.

Policy implications

Advancing the policies on climate reporting

- Contribute to the identification of a *financially relevant* metric to measure the impact of temperature (one phenomenon of CC):
  - Volatility of temperature anomalies (*TD-VAR*) can be replicated for other countries or at wider/narrower geographic dimension;
  - *TD-VAR* can serve as reference for TCFD-like and CSRD frameworks to consistently and transparently report the effects of physical CC.
- Promoting better informed decision-making on climate risk regulation:

Thank you

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Appendix

Electricity demand 1/2

- Energy consumption sensitive to weather conditions, Chang et al. (2016).
- We employ monthly data from EIA to match state temperature statistics.
- We model electricity demand using ARMA (J,P):

$$Q_{s,t} = \sum_{j=1}^{J} a_j Q_{t-j} + \sum_{p=1}^{P} b_p \epsilon_{t-p} + \epsilon_{s,t}, \tag{1}$$

- and analyze residual electricity demand, $\epsilon_{s,t}$:

$$\epsilon_{s,t} = \beta_1 * TD\text{-}VAR_{s,t} + \beta_2 * \widetilde{TD}_{s,t} + \gamma_t + \eta_n + \epsilon. \tag{2}$$

Electricity demand 2/2

	Residential	Commercial	Industrial	Total
TD-VAR	0.0054***	0.0006	0.0020**	0.0025***
	(0.0011)	(0.0006)	(0.0009)	(0.0005)
$\widetilde{TD}$	-0.0011	0.0013**	0.0004	0.0002
	(0.0008)	(0.0006)	(0.0004)	(0.0006)
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
No. Observations	9000	9000	9000	9000
Cov. Est.	Clustered	Clustered	Clustered	Clustered
R-squared	0.0038	0.0034	0.0010	0.0027

Standard errors reported in parentheses

Weather derivatives 1/2

- Temperature-related contracts insure buyers against excessive heat or cold

$$CDD_{i,m} = \sum_{d=1}^{D_m} (T_d - T_0, 0)^+ \qquad HDD_{i,m} = \sum_{d=1}^{D_m} (T_0 - T_d, 0)^+$$

where T_0 is set at 65F for futures traded on the CME.

- Examine relationship monthly levels of CDD and HDD to temperature metrics:

$$\begin{aligned} CDD_{s,m} &= \beta_t T_m + \beta_e \widetilde{TD} + \beta_v TD\text{-}VAR + \beta_v \sigma(TD) + \epsilon \\ HDD_{s,m} &= \alpha + \beta_t T_m + \beta_e \widetilde{TD} + \beta_v TD\text{-}VAR + \beta_v \sigma(TD) + \epsilon \end{aligned} \tag{3}$$

Weather derivatives 2/2

	CDD		HDD	
	(1)	(2)	(1)	(2)
T_m	22.262***	25.516***	-25.980***	-26.018***
	(1.7786)	(2.1067)	(0.8380)	(0.9349)
$TD\text{-}VAR$		4.0458**		3.5812***
		(1.9917)		(0.8282)
$\widetilde{TD}$		-11.082***		5.4309***
		(1.6592)		(0.6308)
$\sigma(TD)$		2.0248		19.595**
		(6.0450)		(9.2184)
α			326.87***	140.60*
			(11.508)	(79.420)
Estimator	PanelOLS	PanelOLS	PanelOLS	PanelOLS
No. Observations	438	438	542	542
Cov. Est.	Clustered	Clustered	Clustered	Clustered
R-squared	0.8807	0.9188	0.9501	0.9630

Estimating temperature exposure

- We use the Russel 3000 index, 99.8% market cap for firms located in U.S.
- We estimate the following model:

$$r_{i,t,s} = \alpha + \beta_{\mathcal{T}} * \mathcal{T}_{t,s} + \beta_1 C_{i,t-1} + \phi_t + \eta_i + \epsilon_{i,t}, \tag{4}$$

  where $\mathcal{T}$ is a generic term for $\widetilde{TD}$ and $TD\text{-}VAR$; $C_{i,t}$ are control variables for firm profitability & riskiness.
- $\mathcal{T}_{t,s}$ for firm i is chosen considering headquarter state.
  - Firm's operational footprint & commercial act. predominately in state s.
  - Working on refinement measures, like activity concentration.

All firms & Sector analysis - Results

Dep. Variable: r	All	Ind	Energy	Health	IT	Utilities	Staple	C. Disc	Mat	Fin	Comm
$\widetilde{TD}$	0.0197	0.0510	0.1452	0.0852	-0.0076	-0.1004**	-0.0036	-0.0268	-0.0780	0.0119	-0.0101
	(0.9529)	(1.1508)	(0.9032)	(0.8592)	(-0.1381)	(-2.5604)	(-0.0500)	(-0.5041)	(-1.0290)	(0.3195)	(-0.1021)
TD-VAR	-0.0984	-0.2476	-0.9477**	0.4770	0.2354	0.3552**	-0.9432***	-0.6084***	0.0163	-0.0670	0.5953
	(0.0759)	(0.1541)	(0.4652)	(0.3478)	(0.2283)	(0.1538)	(0.2646)	(0.2236)	(0.2770)	(0.1357)	(0.4177)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Observations	141827	26670	6731	17509	18058	6321	7441	18543	8911	22365	5380
Cov. Est.	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
R-squared	0.0220	0.0237	0.0243	0.0139	0.0295	0.0209	0.0295	0.0359	0.0405	0.0279	0.0317

Standard errors reported in parentheses

Estimation for *TD* on stock return

Panel A: Temperature anomaly

Dep. Variable: r	All	Ind	Energy	Health	IT	Utilities	Staple	C. Disc	Mat	Fin	Comm
$\widetilde{TD}$	0.0197	0.0510	0.1452	0.0852	-0.0076	-0.1004**	-0.0036	-0.0268	-0.0780	0.0119	-0.0101
	(0.9529)	(1.1508)	(0.9032)	(0.8592)	(-0.1381)	(-2.5604)	(-0.0500)	(-0.5041)	(-1.0290)	(0.3195)	(-0.1021)
LOGSIZE	-4.0221***	-4.3981***	-2.7935***	-4.0251***	-4.5562***	-3.1566***	-4.6041***	-5.1566***	-5.7560***	-2.8803***	-4.4655***
	(-27.758)	(-11.816)	(-5.6288)	(-8.2804)	(-9.5827)	(-7.0067)	(-8.3714)	(-14.519)	(-12.504)	(-11.977)	(-7.3882)
B/M	0.0028	0.0042	-0.0456*	-0.0224	0.0447*	0.0349	0.0355	0.0269	0.1293***	-0.0177*	0.0552**
	(0.4185)	(0.2098)	(-1.9141)	(-1.1148)	(1.7702)	(1.5437)	(1.5955)	(1.1453)	(4.6954)	(-1.7409)	(2.0166)
ROE	0.0421***	0.0360***	0.0181	0.0351***	0.0517***	0.0619***	0.0486***	0.0516***	0.0706***	0.0795***	0.0345***
	(12.679)	(4.1566)	(1.1995)	(4.4550)	(6.9696)	(2.8095)	(3.2003)	(8.2675)	(6.9395)	(6.4879)	(3.5929)
LEVERAGE	-6.228e-05	0.0014	-0.0255	-0.0001	0.0361***	-0.0033	0.0180	-0.0420***	0.0152	-0.0213**	0.0223
	(-0.1042)	(0.1429)	(-1.2480)	(-0.2092)	(2.6880)	(-0.1727)	(1.2436)	(-2.8260)	(0.9949)	(-2.2622)	(1.0244)
INVEST/A	0.0563**	0.0501*	0.0913	0.0618	0.0439	0.0126	0.1058*	-0.0246	0.0025	-0.1464*	-0.0403
	(1.9619)	(1.6797)	(1.5282)	(1.1325)	(0.6122)	(0.3603)	(1.9201)	(-0.8990)	(0.0481)	(-1.8887)	(-0.6033)
LOGPPE	0.3849***	0.9937***	1.7880*	-0.3065	-0.0303	0.1252**	0.9673***	0.8023***	0.7069*	0.4224**	0.9395**
	(3.7273)	(3.7276)	(1.8732)	(-0.8975)	(-0.0955)	(2.3325)	(3.7254)	(2.6222)	(1.7622)	(2.2345)	(2.4444)
MOM	-0.0431**	0.0235	-0.1375	-0.0134	-0.0499	-0.0545	0.0437	-0.0692*	0.0504	-0.2512***	-0.1031
	(-2.3345)	(0.5090)	(-1.2486)	(-0.2569)	(-1.1200)	(-0.5840)	(0.6600)	(-1.6582)	(0.8254)	(-5.3834)	(-1.2196)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Observations	141827	26670	6731	17509	18058	6321	7441	18543	8911	22365	5380
Cov. Est.	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
R-squared	0.0220	0.0237	0.0239	0.0138	0.0294	0.0210	0.0278	0.0355	0.0406	0.0279	0.0314

Standard errors reported in parentheses

Estimation for *TD-VAR* on stock return

Panel B: Volatility of temperature anomaly

Dep. Variable: r	All	Ind	Energy	Health	IT	Utilities	Staple	C. Disc	Mat	Fin	Comm
TD-VAR	-0.0984	-0.2476	-0.9477**	0.4770	0.2354	0.3552**	-0.9432***	-0.6084***	0.0163	-0.0670	0.5953
	(0.0759)	(0.1541)	(0.4652)	(0.3478)	(0.2283)	(0.1538)	(0.2646)	(0.2236)	(0.2770)	(0.1357)	(0.4177)
LOGSIZE	-4.0223***	-4.3964***	-2.7972***	-4.0210***	-4.5571***	-3.1496***	-4.6158***	-5.1595***	-5.7561***	-2.8808***	-4.4402***
	(0.1449)	(0.3723)	(0.4961)	(0.4868)	(0.4755)	(0.4501)	(0.5489)	(0.3551)	(0.4605)	(0.2404)	(0.6057)
B/M	0.0029	0.0042	-0.0459*	-0.0232	0.0451*	0.0360	0.0353	0.0278	0.1289***	-0.0177*	0.0536*
	(0.0067)	(0.0200)	(0.0238)	(0.0201)	(0.0253)	(0.0226)	(0.0222)	(0.0235)	(0.0275)	(0.0102)	(0.0275)
ROE	0.0421***	0.0359***	0.0179	0.0350***	0.0518***	0.0616***	0.0486***	0.0516***	0.0705***	0.0794***	0.0347***
	(0.0033)	(0.0087)	(0.0150)	(0.0079)	(0.0074)	(0.0220)	(0.0152)	(0.0062)	(0.0102)	(0.0123)	(0.0096)
LEVERAGE	-6.133e-05	0.0012	-0.0261	-0.0001	0.0362***	-0.0043	0.0179	-0.0417***	0.0148	-0.0213**	0.0221
	(0.0006)	(0.0097)	(0.0204)	(0.0006)	(0.0134)	(0.0189)	(0.0145)	(0.0149)	(0.0153)	(0.0094)	(0.0218)
INVEST/A	0.0564**	0.0502*	0.0922	0.0575	0.0441	0.0134	0.1048*	-0.0245	0.0032	-0.1464*	-0.0430
	(0.0287)	(0.0298)	(0.0596)	(0.0547)	(0.0717)	(0.0351)	(0.0550)	(0.0273)	(0.0515)	(0.0776)	(0.0668)
LOGPPE	0.3850***	0.9949***	1.8210*	-0.3006	-0.0319	0.1170**	0.9734***	0.7981***	0.7175*	0.4214**	0.9523**
	(0.1033)	(0.2666)	(0.9533)	(0.3400)	(0.3172)	(0.0536)	(0.2603)	(0.3062)	(0.4015)	(0.1890)	(0.3845)
MOM	-0.0430**	0.0237	-0.1369	-0.0135	-0.0502	-0.0561	0.0468	-0.0698*	0.0516	-0.2513***	-0.1056
	(0.0185)	(0.0460)	(0.1104)	(0.0521)	(0.0446)	(0.0932)	(0.0662)	(0.0417)	(0.0611)	(0.0467)	(0.0843)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Observations	141827	26670	6731	17509	18058	6321	7441	18543	8911	22365	5380
Cov. Est.	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
R-squared	0.0220	0.0237	0.0243	0.0139	0.0295	0.0209	0.0295	0.0359	0.0405	0.0279	0.0317

Standard errors reported in parentheses

Temperature proof portfolio

- We examine investors' response to temperature anomalies:
    - Can investors reduce their exposure to temperature (*acute* climate effects) by considering local temperature anomalies?
    - Which statistic of temperature anomalies is more relevant?
- Sort states into quintiles based on their $\widetilde{TD}$ and $TD\text{-}VAR$ exposure.
- Form long–short spread portfolios: going long on firms in less-exposed states and short on firms in the most-exposed states.
- Project the 5 portfolio returns on the Fama-French 3 factors and a fourth momentum factor.

Temperature proof portfolio

	Panel A: *TD-VAR*			Panel B: $\widetilde{TD}$		
	Excess Return	**3-factor**	**4-factor**	**Excess Return**	**3-factor**	**4-factor**
Quintile 1	1.114***	0.435***	0.439***	0.881**	0.213	0.214
	(3.172)	(2.415)	(2.388)	(2.518)	(1.200)	(1.201)
Quintiles 2–4	0.7253***	0.162	0.16	0.755***	0.185	0.182
	(2.833)	(1.473)	(1.446)	(2.888)	(1.611)	(1.586)
Quintile 5	0.678**	0.055	0.050	0.946**	0.293	0.298
	(2.191)	(0.333)	(0.308)	(2.782)	(1.569)	(1.601)
(1–5)	0.436	0.38	0.389	-0.058	-0.08	-0.084

Identifying channels of price reaction

Are the shocks to the distribution of temperature anomalies drivers of investor attention or do they capture adverse disruptions to firm operations?

- The prior analysis suggests that exposure to *TD-VAR* has serious implications for firm stock prices.
- We don't observe the mechanism that determines price reaction.
- Two mutually non exclusive channels:
  - investor attention: heightened temperature anomalies acts as 'attention grab';
  - realization of physical climate/temperature impact on firm's financial performance.

Attention-adjusted effect

- Engle et al., 2020 represent climate attention through WSJ news, U.S. country wide.
  - Moderate relationship with publication of U.S. climate-related news.
- Granular representations of climate attention could capture the geographical heterogeneity of $TD\text{-}VAR$ and $\widetilde{TD}$.
  - Obtain Google Search Volume Index (SVI) for "Temperature" and "Climate Change" for each state.
- Following Choi et al., 2020, we regress unexpected state-level SVI for each topic on the temperature statistics.

$$\epsilon_{SVI,s,t} = \beta_T * TD\text{-}VAR_{s,t} + \beta_D * \widetilde{TD}_{s,t} + \rho_t + \gamma_s + \epsilon_{s,t}. \tag{5}$$

Attention-adjusted effect considering SVI

	Climate Change: Panel (A)			Temperature: Panel (B)		
	1	2	3	1	2	3
TD-VAR	0.77***		0.76***	0.73***		0.76***
	(0.24)		(0.25)	(0.17)		(0.16)
$\widetilde{TD}$		-0.05	-0.04		0.12**	0.13***
		(0.05)	(0.05)		(0.05)	(0.05)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
No. Observations	8850	8850	8850	8850	8850	8850
Cov. Est	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
R-squared	0.01	0.001	0.01	0.02	0.01	0.04

t-stats reported in parentheses

Temperature impact beyond attention

- We analyze the attention-adjusted reaction to temperature anomalies (trends and volatility) on firm-level operations.
- Sautner et al., 2020 develop a time-varying measure of firm-level exposure to physical climate change risks.
- We disentangle material impact of the temperature from the effects of attention to temperature-related events:

$$PhysCCExp_{i,t} = \alpha + \beta_1 * WSJ_t + \beta_2 * \epsilon_{WSJ,t} + \gamma_i + \epsilon_{NetExp,i,t}. \tag{6}$$

- $\epsilon_{NetExp,i,t}$ contains the *direct* impact of physical climate change exposure beyond attention, we regress against temperature metrics:

$$\epsilon_{NetExp,i,t} = \alpha + \beta_T * TD\text{-}VAR_{s,t} + \beta_D * \widetilde{TD}_{s,t} + \gamma_i + \epsilon_{i,s,t}. \tag{7}$$

Results

	(1) All Industires	(2) Ex Util/Energy	(3) Util/Energy	(4) Cons Disc/Staples
TD-VAR	0.038***	0.032**	0.102**	0.020
	(0.014)	(0.015)	(0.050)	(0.019)
$\widetilde{TD}$	-0.006*	-0.005	-0.014	-0.004
	(0.003)	(0.003)	(0.013)	(0.005)
Firm FE	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes
Observations	65341	60589	4752	12046
R-sq	0.000	0.000	0.001	0.000

t-stats reported in parentheses