Climate Risks and Market Efficiency

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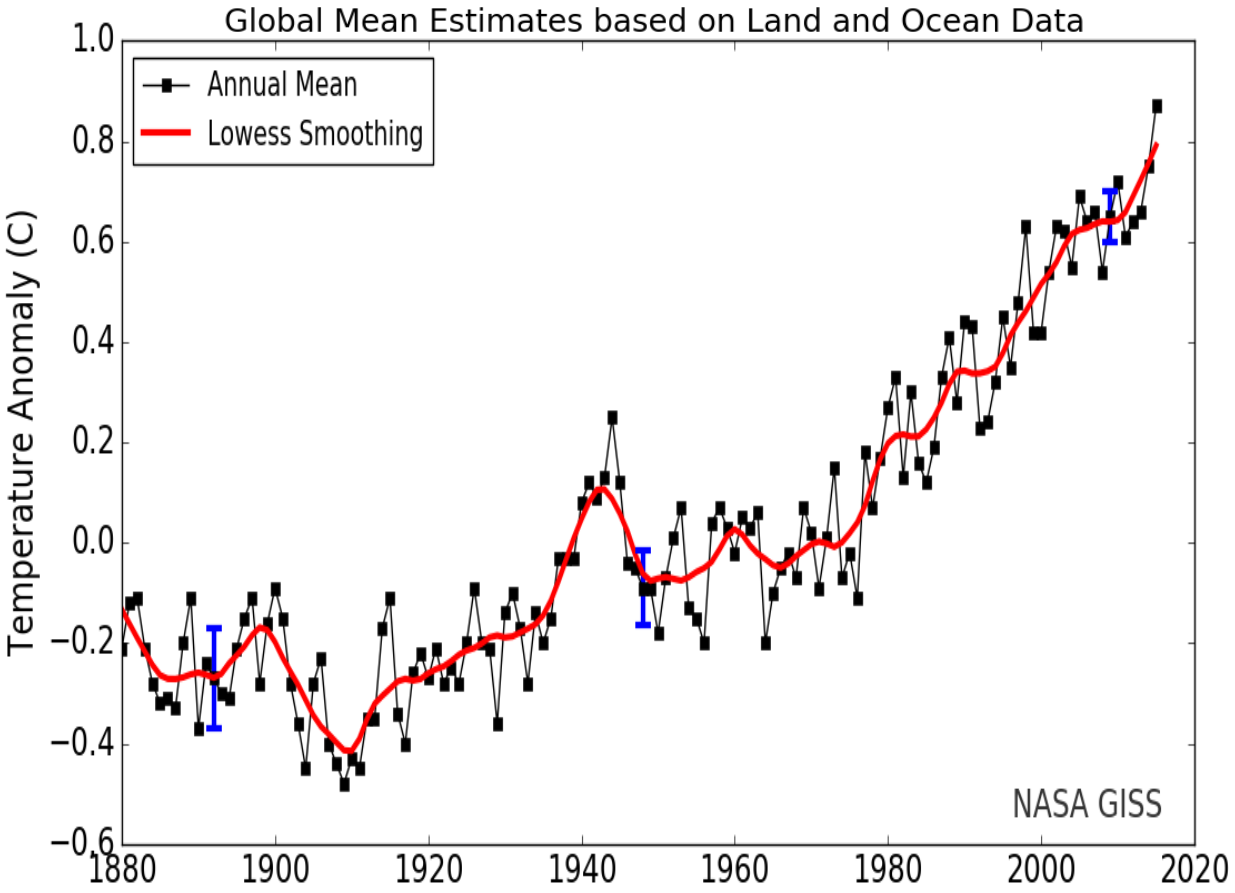
Motivation


Global Mean Estimates based on Land and Ocean Data
Annual Mean
Lowess Smoothing
Temperature Anomaly (C)
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
1880
1900
1920
1940
1960
1980
2000
2020
NASA GISS

Motivation

- Regulators link climate change risks to financial stability (Carney (2015))
- Inattention to new climate change risks?
  - Stranded assets: future carbon taxes and oil companies?
  - Natural disasters and corporate profits
- Limited study of these issues
- Efficient market studies of climate risks can help answer these questions and inform quantitative portfolios for risk management (Fama (1991), Shiller (1994))

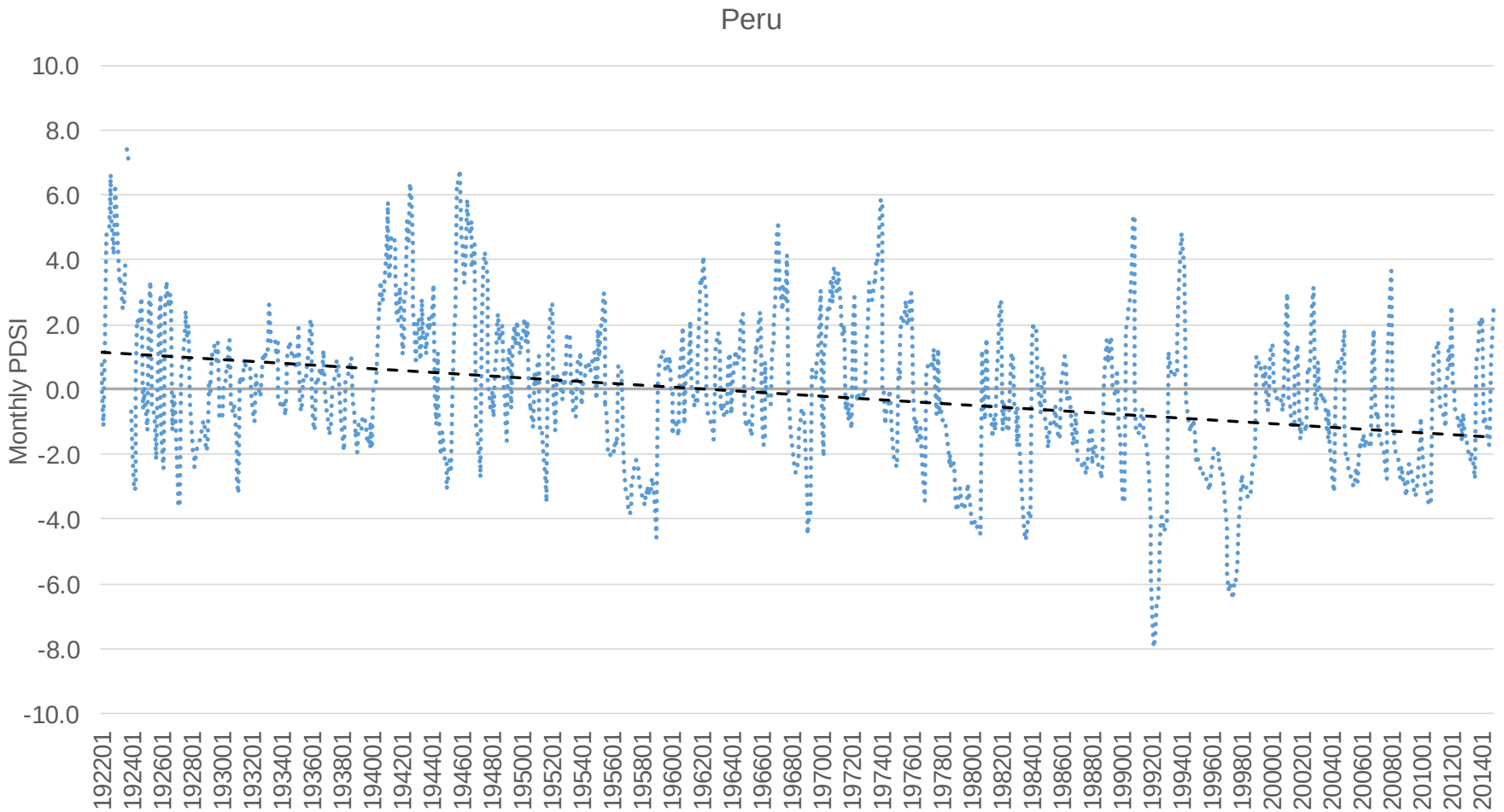
Our Paper: Long-term Trends of Droughts for Food Industry Profitability

- Climate science finds that climate change exacerbates risks of droughts (Trenbeth et.al. (2014))
- Prolonged drought most destructive in a study of 2,800 weather disasters for food production (Lesk et.al. (2016))
- FOOD industry (including agricultural, processing, beverages etc...) most reliant on water and drought sensitive (Blackhurst et.al. (2010), May 2015 *Ceres Report*)
- Comprised of small and medium sized companies exposed to climate at country of origin since drought affects inputs

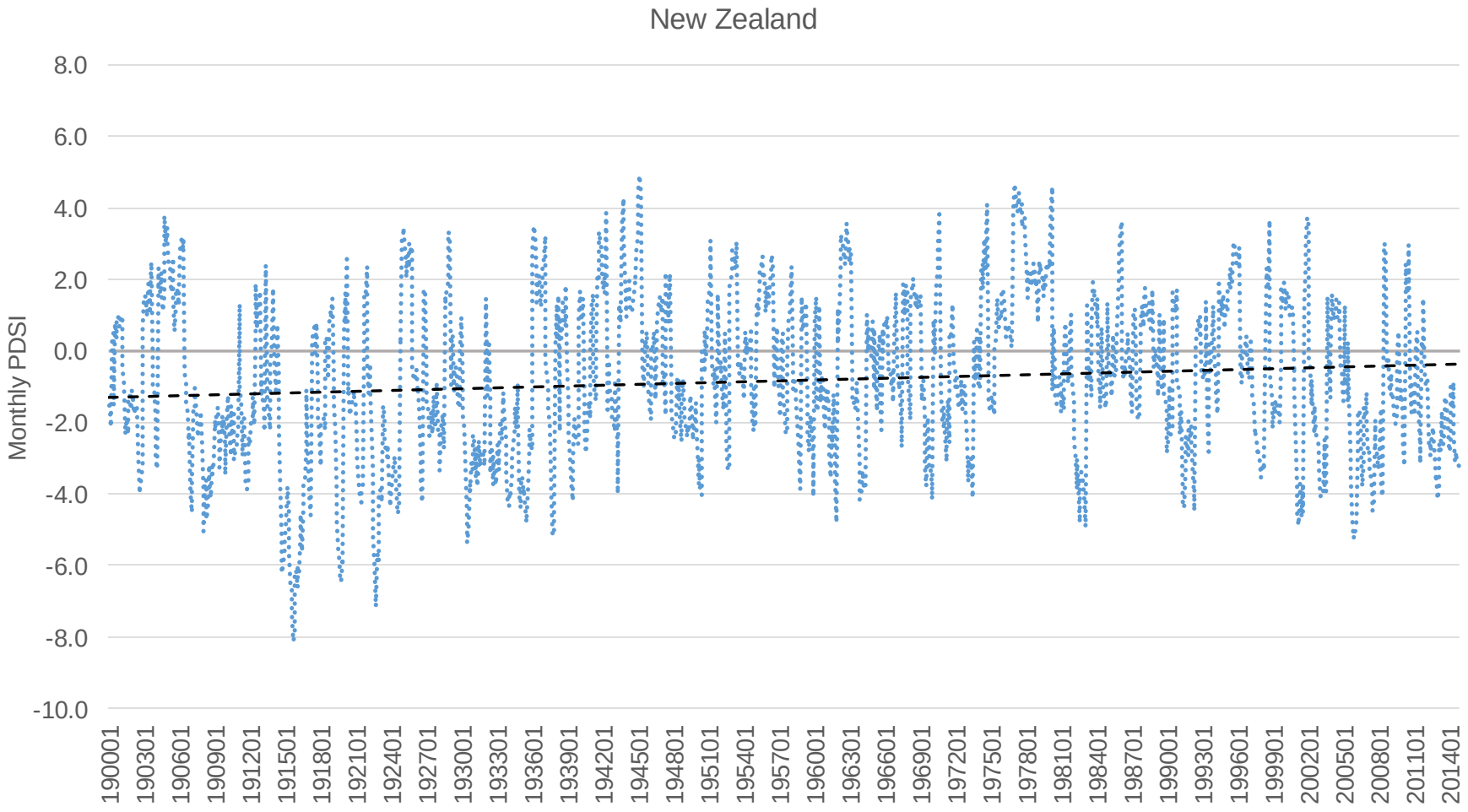
Ranking Countries Based on Trend in PDSI

- Rank countries at any given time t based on their long-term trends in Palmer Drought Severity Index (PDSI) (Palmer (1965))
  - Combines temperature and soil moisture to measure drought intensity: -10 (severe drought) to +10 (no drought)
  - Available monthly and going back to 1900 for many countries

Plot of PDSI, Peru



Plot of PDSI, New Zealand



Efficient Market Study Using PDSI

- Examine change in Net Income for Low (negative trending) versus High (positive trending) groups
- Do these trends also predict food stock returns?
  - Null Hypothesis: Controlling for risk measures, there should be no excess return predictability (NEP)
  - Alternative Hypothesis: Underreaction if stocks in Low Group under-perform stocks in High Group
- No inference per se on average performance of Food sector

Climate-Risk of Each Country's Food Sector

- Sample of 31 countries (including US) with at least 10 FOOD stocks from 1985-now
- For each country i at month t, we estimate the PDSI time trends using the following specification:

$$PDSI_{i,t} = a_i + b_i t + c_i PDSI_{i,t-1} + \epsilon_{i,t} \quad (1)$$

- b_i is our measure of a country's vulnerability to droughts as a result of climate change
- Statistically significant differences in time trends across countries

Main Findings

- Food industries in countries with negative (positive) PDSI time trend have lower (higher) profitability over the next three years.
- A long-short strategy based on PDSI time trend generates 7-8% alpha annually.
- Results robust after adjusting for usual global and currency risk factors
- Use Fama-MacBeth regressions to control for country characteristics like inflation
- Results similar using initial time trend measured at the end of 1984

Summary Statistics by Each Country

- In order of average # of food stocks

Number	Country	Average # of Stocks	Mean Firm Size (Millions USD)
1	United States	134	3789
2	India	107	18
3	Japan	77	363
4	China	58	458
5	Malaysia	49	141
6	United Kingdom	40	182
7	South Korea	39	162
8	Thailand	32	69
9	France	28	217
10	Australia	28	124
11	Greece	25	60
12	Indonesia	22	122
13	Poland	21	81
14	Israel	20	103
15	Peru	19	76

Summary Statistics by Each Country, Cont.

Number	Country	Average # of Stocks	Mean Firm Size (Millions USD)
16	Chile	19	120
17	Turkey	18	79
18	Canada	15	208
19	Germany	15	438
20	South Africa	15	346
21	Brazil	14	907
22	Switzerland	13	714
23	New Zealand	13	141
24	Netherlands	13	2888
25	Mexico	11	293
26	Belgium	11	126
27	Philippines	11	243
28	Denmark	11	417
29	Russian Federation	11	295
30	Portugal	11	25
31	Finland	10	209

Summary Statistics of PDSI Trend Estimates over Time

Country	Intercept	t-stat	Time Trend	t-stat	Lagged PDSI	t-stat
Peru	0.28	2.84	-3.69	-3.03	0.86	42.82
Israel	0.32	2.90	-3.31	-2.77	0.90	56.69
Japan	0.17	2.01	-2.61	-2.16	0.78	39.57
Poland	0.08	1.87	-1.29	-2.09	0.93	75.32
Philippines	0.16	2.31	-2.10	-1.92	0.77	29.02
Greece	0.09	1.43	-1.76	-1.86	0.84	49.26
Thailand	0.09	1.63	-1.27	-1.78	0.92	75.35
Chile	0.11	2.69	-1.08	-1.77	0.91	82.69
Switzerland	0.06	1.24	-1.24	-1.52	0.84	43.06
Brazil	0.14	1.31	-1.68	-1.33	0.86	44.04
France	0.01	0.22	-0.61	-0.89	0.88	49.87
Germany	0.01	0.38	-0.46	-0.84	0.91	72.93
Belgium	0.06	1.43	-0.49	-0.68	0.90	64.29
Netherlands	0.06	1.43	-0.49	-0.68	0.90	64.29

- Time trend in bps; t-stat is the average of the Newey-West adjusted t-stats from each period
- Table in order of t-stats of PDSI time trend (most negative to most positive)

Summary Statistics of PDSI Trend Estimates over Time, Cont.

Country	Intercept	t-stat	Time Trend	t-stat	Lagged PDSI	t-stat
Malaysia	0.09	1.09	-0.74	-0.56	0.78	40.57
South Africa	0.01	0.17	-0.37	-0.42	0.89	61.65
Finland	0.04	0.89	-0.22	-0.33	0.93	77.90
Turkey	0.08	1.03	-0.23	-0.26	0.85	44.72
Indonesia	-0.02	-0.47	0.20	0.19	0.82	35.56
Portugal	-0.05	-1.12	0.16	0.21	0.90	67.15
United Kingdom	-0.03	-0.46	0.40	0.44	0.90	60.70
United States	0.00	-0.18	0.29	0.54	0.94	118.28
China	-0.20	-1.58	1.18	0.59	0.86	53.29
India	-0.10	-1.20	1.15	0.99	0.83	46.15
Russian Federation	-0.05	-0.82	0.84	1.03	0.89	58.32
Denmark	-0.04	-0.87	0.92	1.09	0.85	45.48
South Korea	-0.09	-1.56	1.01	1.11	0.88	60.94
Canada	-0.12	-2.39	1.13	1.55	0.89	54.58
Australia	-0.21	-3.47	1.55	1.75	0.87	51.67
Mexico	-0.18	-2.29	2.07	1.98	0.86	48.17
New Zealand	-0.27	-3.21	2.51	2.16	0.83	43.94

Annual Change of Profitability and Return of Food Industry

- For each country, change in food industry profitability (CP) from year t to $t+1$ as $CP_{t+1} = NI_{t+1}/A_{t+1} - NI_t/A_t$, where NI is the food industry-level net income and A is the food industry-level total book assets in year t.
- For each country, we calculate its food industry return as the value-weighted average return of individual firms within food industry.

Summary Statistics of Variables

	Mean	S.D.	Median	P10	P90
CP (%)	0.11	3.62	-0.02	-2.89	2.88
FOODRET12 (%)	12.02	33.03	11.31	-25.17	48.78
Trend (bps)	-0.50	1.52	-0.47	-2.71	1.51
PDSI36m*	-0.29	1.41	-0.34	-2.05	1.42
MRET12 (%)	8.83	33.37	10.47	-30.97	44.71
FOODPB	2.54	1.83	2.09	0.83	4.85
DP (%)	3.49	6.81	2.36	0.94	4.82
INF12 (%)	9.34	33.32	3.27	1.00	11.28

- CP: change of FOOD profitability over 1 year
- FOODRET12: FOOD return over 12 months
- Trend: PDSI time trend
- PDSI36m*: PDSI36m (36-month moving average of PDSI) minus the mean and dividing by the std of PDSI36m, with the mean and std estimated using data from 1900 to 1939
- MRET12: market return over 12 months
- FOODPB: log of FOOD price to book ratio
- DP: market dividend-to-price ratio
- INF12: annual inflation rate

Change of Profitability to Portfolios Sorted on PDSI Time Trend

Portfolio	(t, t+1)	(t, t+2)	(t, t+3)
Low	-0.09%	-0.32%	-0.46%
Middle	0.21%	0.10%	-0.03%
High	0.40%	0.32%	0.61%
High - Low	0.49%	0.63%	1.06%
t-stat	3.02	1.91	2.90

- Quintile portfolios are sorted on lagged PDSI time trend. Middle three portfolios grouped together by equal weighting their profitability changes
- CP for each portfolio is the equal-weighted average CP of the countries within each portfolio
- (t, t+1) is the change of profitability over the 1-year period following portfolio formation date. (t, t+2) and (t, t+3) are resp. cumulative change of profitability over the 2-year and 3-year periods

Change of FOOD Profitability on PDSI Time Trend, FM Regression

	(1)	(2)	(3)
Low Trend	-0.4131***	-0.2427***	-0.2692*
	(-3.41)	(-3.47)	(-2.04)
FOODPB		-0.2250	0.1041
		(-1.40)	(0.53)
FOODRET12		0.0017	0.0081
		(0.23)	(1.54)
DP			0.0202
			(0.22)
MRET12			-0.0112*
			(-1.81)
INF12			-0.0410*
			(-1.89)

- Dependent variable is future 1-year change in food industry profitability
- "Low Trend" is a dummy equal to 1 for countries in the lowest quintile of its estimated PDSI time trend at the end of each year

Change of FOOD Profitability on Initial PDSI Time Trend, FM Regression

	(1)	(2)	(3)
Low Trend	-0.2078**	-0.2265**	-0.3989***
	(-2.19)	(-2.58)	(-3.60)
FOODPB		-0.2117	0.1244
		(-1.35)	(0.62)
FOODRET12		0.0004	0.0047
		(0.05)	(0.72)
DP			0.0194
			(0.24)
MRET12			-0.0125**
			(-2.48)
INF12			-0.0466**
			(-2.26)

- Dependent variable is future 1-year change in food industry profitability
- "Low Trend" here is a dummy equal to 1 for countries in the lowest quintile based on its estimated PDSI time trend at the end of 1984

Returns to Portfolios Sorted on PDSI Time Trend

Panel A: 1-year holding horizon				
	Excess Return	CAPM	Carhart 4-factor	Currency Factors
Low	0.33	0.23	0.19	-0.19
Middle	0.75	0.63	0.68	0.03
High	0.89	0.78	0.78	0.25
High - Low	0.56	0.55	0.58	0.44
t-stat	2.03	1.98	2.03	1.56

- Each month, construct a long/short portfolio that short countries whose PDSI time trend is in the lowest quintile at last month and long the highest quintile
- Middle three portfolios grouped together by equal weighting their returns
- Portfolios are overlapping a la Jegadeesh and Titman (1993)
- The currency factor model is from Lustig, Roussanov, and Verdelhan (2011)

Returns to Portfolios Sorted on PDSI Time Trend, Cont.

Panel B: 2-year holding horizon

	Excess Return	CAPM	Carhart 4-factor	Currency Factors
Low	0.30	0.19	0.17	-0.23
Middle	0.71	0.59	0.64	-0.01
High	0.91	0.80	0.80	0.27
High - Low	0.62	0.60	0.63	0.49
t-stat	2.21	2.16	2.19	1.72

Panel C: 3-year holding horizon

	Excess Return	CAPM	Carhart 4-factor	Currency Factors
Low	0.28	0.18	0.15	-0.24
Middle	0.68	0.56	0.60	-0.05
High	0.93	0.81	0.81	0.28
High - Low	0.64	0.63	0.66	0.52
t-stat	2.30	2.25	2.28	1.81

Calibration of Change in Net Income with Change of Price

- During a 3-year period, the net income of countries with negative PDSI trend relative to countries with positive PDSI trend decreases by 1.06% as a percentage of total assets
- Average Total Assets/Net Income ratio of food sector is 20.3
- This means the growth rate of net income is -21.5% for negative PDSI trend countries over 3 years
- This matches the 3-year return difference of 23% of our long/short portfolio

FOOD Return on PDSI Time Trend, FM Regression

	(1)	(2)	(3)
Low Trend	-7.0251***	-2.0315*	-5.3988***
	(-3.56)	(-1.84)	(-2.76)
FOODPB		-3.9076***	-1.4628
		(-3.44)	(-1.50)
FOODRET12		0.0010	-0.1394
		(0.01)	(-0.85)
DP			1.2994**
			(2.18)
MRET12			-0.0217
			(-0.61)
INF12			2.5806
			(1.43)

- Dependent variable is the non-overlapping food return over the future 12 months
- "Low Trend" is a dummy equal to 1 for countries in the lowest quintile of its estimated PDSI time trend at the end of each year

Returns to L/S Portfolio Sorted on PDSI Time Trend for Food Sub-sectors

Subsectors	Starting Date	Excess Return	t-stat	4-factor alpha	t-stat
Food Products	198501	0.67	2.27	0.71	2.33
Beverage	198501	0.53	1.75	0.54	1.72
Farm	199101	0.86	2.24	0.71	1.75

- For each sub-sector in the food industry, we construct a long/short portfolio that short countries whose PDSI time trend is in the bottom quintile and long the top quintile
- Include a country in our sample when the number of stocks in a subsector is larger than or equal to 5

Returns to Portfolios Sorted on Standardized PDSI36m

	Excess Return	CAPM	4-factor alpha	Currency Factor
Lowest Quintile	0.43	0.30	0.31	-0.24
Middle	0.63	0.53	0.49	0.06
Highest Quintile	0.96	0.83	0.82	0.29
High- Low	0.53	0.53	0.51	0.53
t-stat	2.16	2.18	1.99	2.09

- Standardized PDSI36m is PDSI36m ((36-month moving average of PDSI) minus the mean and dividing by the standard deviation of PDSI36m
- The mean and standard deviation of PDSI36m are estimated using data from 1900 to 1939

Returns to Portfolios Sorted on PDSI Time Trend For Other Industries

Industry	4-factor alpha	t-stat
Food & Beverage	0.58	2.03
Utilities	0.69	1.47
Construction & Materials	0.35	1.25
Basic Resources	0.22	0.80
Automobiles & Parts	0.36	0.80
Health Care	0.27	0.80
Chemicals	0.25	0.76
Technology	0.22	0.66
Personal & Household Goods	0.10	0.44
Oil & Gas	0.17	0.37
Insurance	0.03	0.06
Industrial Goods & Services	-0.01	-0.07
Retail	-0.06	-0.17
Financial Services	-0.08	-0.24
Media	-0.14	-0.34
Travel & Leisure	-0.12	-0.37
Telecommunications	-0.47	-0.49
Real Estate	-0.20	-0.70
Banks	-0.29	-1.02

- The long/short portfolio is constructed within each industry as defined by the Industry Classification Benchmark supersector level

Conclusion

- Stock markets are inefficient with respect to information about climate change and trends in droughts
- Countries with more negative PDSI time trend have lower profitability in food sector over time
- Negative PDSI time trend forecasts lower FOOD industry returns
- A number of implications for policymakers and practitioners
  - Initial and modest evidence confirming regulatory worries about markets underreacting to climate risks
  - PDSI might be a very useful metric of drought to form portfolios and manage risks