

# Climate Risks and Market Efficiency

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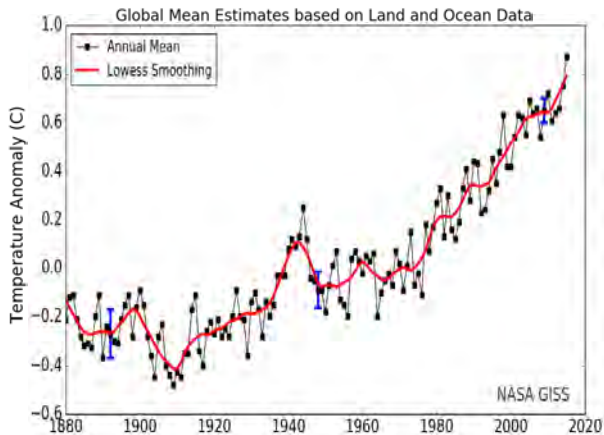
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# Motivation



# Motivation

- ▶ Regulators link climate change risks to financial stability (Carney (2015))
  - ▶ Stranded assets: future carbon taxes and oil companies?
  - ▶ Natural disasters: drought amplified by climate change (Trenbeth et.al. (2014)) and insurance companies
- ▶ Regulatory responses depend on nature of inefficiencies
  - ▶ Inattention to new climate change risks
  - ▶ Voluntary and mandatory disclosure requirements
- ▶ Efficient market studies of climate risks can help answer these questions and inform quantitative portfolios for risk management (Fama (1991), Shiller (1994))

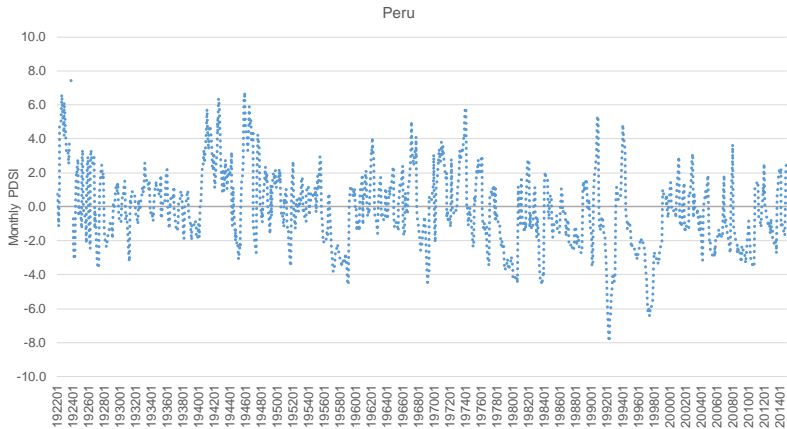
# Our Paper: Climate Risk for Food Industry Profitability Due to Droughts

- ▶ 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))
- ▶ Short-fall of earnings and profitability ratios for Cargill, Tyson Chicken, and Campbell Soup (May 2015 *Ceres Report*) since drought affects inputs

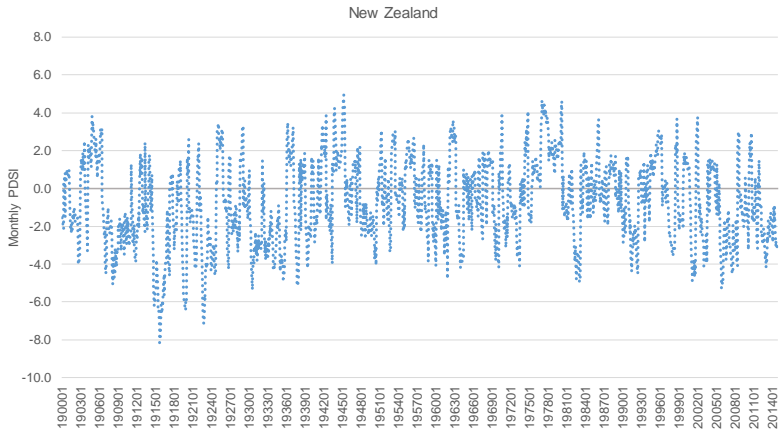
## Palmer Drought Severity Index (PDSI) (Palmer (1965))

- ▶ Combines temperature and soil moisture to measure drought intensity: -10 (severe drought) to +10 (no drought)
- ▶ Available monthly and going back to 1890s for many countries

# Plot of PDSI, Peru



# Plot of PDSI, New Zealand



## 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:

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

- ▶ We denote the parameter estimates  $a_i$  as Intercept,  $b_i$  as Time Trend, and  $c_i$  as Lagged PDSI
- ▶  $b_i$  is our measure of a country's vulnerability to droughts as a result of climate change
- ▶ Countries with previous more temperate climate tend to have more negative time trend in PDSI



## Main Findings

- ▶ Countries with more negative PDSI time trend have lower profitability in food sector over the next three years
- ▶ A long-short strategy based on PDSI time trend generates 7-8% alpha annually
- ▶ Results are robust after adjusting for global risk factors and currency risk factors
- ▶ Negative PDSI time trend forecasts lower FOOD industry returns using Fama-MacBeth regression
- ▶ Results similar using initial time trend measured at the end of 1984
- ▶ Little effect of droughts on other industries
- ▶ Prolonged drought measure PDSI36m (deviation of last 36 month average of PDSI from long-run mean)

# Summary Statistics by Each Country

- ▶ In order of average # of food stocks

Number	Country	Average # of Stocks	Median Firm Size (Millions USD)
1	United States	134	4004
2	India	107	934
3	Japan	77	26761
4	China	58	17309
5	Malaysia	49	6051
6	United Kingdom	40	5430
7	South Korea	39	3248
8	Thailand	32	1600
9	France	28	5245
10	Australia	28	2928
11	Greece	25	1308
12	Indonesia	22	1605
13	Poland	21	1036
14	Israel	20	1332
15	Peru	19	465

## Summary Statistics by Each Country, Cont.

Number	Country	Average # of Stocks	Median Firm Size (Millions USD)
16	Chile	19	1684
17	Turkey	18	771
18	Canada	15	2264
19	Germany	15	6491
20	South Africa	15	4724
21	Brazil	14	6158
22	Switzerland	13	9360
23	New Zealand	13	502
24	Netherlands	13	12735
25	Mexico	11	2562
26	Belgium	11	1277
27	Philippines	11	974
28	Denmark	11	2898
29	Russian Federation	11	2064
30	Portugal	11	199
31	Finland	10	109

## Time Trends of PDSI for Each Country at end of 2000

Country	Intercept	t-stat	Time Trend	t-stat	Lagged PDSI	t-stat
Israel	0.34	3.62	-3.66	-3.13	0.90	69.00
Peru	0.28	2.57	-3.82	-2.74	0.87	53.72
Greece	0.10	1.56	-2.08	-2.25	0.84	54.16
Japan	0.17	2.08	-2.60	-2.20	0.79	45.02
Poland	0.08	1.76	-1.32	-2.05	0.93	85.84
Thailand	0.09	1.58	-1.34	-1.71	0.92	84.07
Philippines	0.14	1.82	-1.67	-1.56	0.78	42.61
Chile	0.10	2.20	-1.02	-1.55	0.92	78.60
Brazil	0.14	1.65	-1.73	-1.52	0.85	53.75
Switzerland	0.05	0.92	-1.09	-1.29	0.84	53.45
Germany	0.02	0.46	-0.63	-1.03	0.92	79.12
France	0.00	0.04	-0.45	-0.59	0.88	65.93
Belgium	0.05	1.05	-0.35	-0.52	0.90	73.12
Netherlands	0.05	1.05	-0.35	-0.52	0.90	73.12
Malaysia	0.08	0.97	-0.53	-0.46	0.78	43.60

- ▶ Time trend is in bps
- ▶ Table in order of t-stats of PDSI time trend (most negative to most positive)

## Time Trends of PDSI for Each Country at end of 2000, Cont.

Country	Intercept	t-stat	Time Trend	t-stat	Lagged PDSI	t-stat
Finland	0.05	0.93	-0.27	-0.39	0.93	85.79
Turkey	0.06	0.76	0.12	0.11	0.85	55.20
Indonesia	-0.02	-0.34	0.10	0.12	0.82	50.43
China	-0.15	-1.41	0.22	0.16	0.87	56.18
South Africa	-0.01	-0.22	0.21	0.24	0.90	70.76
United States	0.01	0.11	0.25	0.33	0.94	99.06
Portugal	-0.06	-1.16	0.34	0.46	0.90	67.53
United Kingdom	-0.03	-0.49	0.38	0.48	0.90	70.49
Russian Federation	-0.04	-0.68	0.68	0.78	0.89	69.04
India	-0.09	-1.11	1.10	0.92	0.84	52.98
South Korea	-0.09	-1.52	1.00	1.14	0.88	66.29
Canada	-0.11	-2.08	0.88	1.15	0.89	67.82
Denmark	-0.05	-0.79	1.05	1.22	0.86	58.24
Mexico	-0.17	-2.39	1.84	1.86	0.86	58.46
Australia	-0.22	-3.65	1.67	2.03	0.86	59.82
New Zealand	-0.28	-3.75	2.72	2.60	0.83	51.95

## Summary Statistics of PDSI Trend Estimates over Time

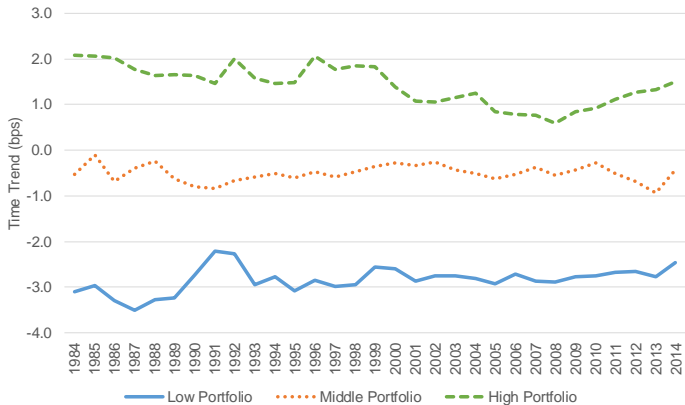
Country	Intercept	t-stat	Time Trend	t-stat	Lagged PDSI	t-stat
Peru	0.28	2.84	-3.69	-3.03	0.86	42.82
Israel	0.32	2.90	-3.31	-2.77	0.90	56.69
Japan	0.17	2.01	-2.61	-2.16	0.78	39.57
Poland	0.08	1.87	-1.29	-2.09	0.93	75.32
Philippines	0.16	2.31	-2.10	-1.92	0.77	29.02
Greece	0.09	1.43	-1.76	-1.86	0.84	49.26
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

# PDSI Time Trend for Portfolios Over Time





# Summary Statistics of Variables

	Mean	S.D.	Median	P10	P90
CP (%)	0.11	3.62	-0.02	-2.89	2.88
FOODRET12m (%)	12.02	33.03	11.31	-25.17	48.78
Trend (bps)	-0.50	1.52	-0.47	-2.71	1.51
MRET12 (%)	8.83	33.37	10.47	-30.97	44.71
FOODPB	2.54	1.83	2.09	0.83	4.85
FOODSIZE	7.81	1.24	7.82	6.21	9.44
DP12 (%)	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
- ▶ FOODRET12m: FOOD return over 12 months
- ▶ Trend: PDSI time trend
- ▶ MRET12: market return over 12 months
- ▶ FOODPB: log of FOOD price to book ratio
- ▶ FOODSIZE: log of FOOD market cap
- ▶ DP12: log of market dividend-to-price ratio
- ▶ INF12: annual inflation rate

## Correlation among Variables

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	CP	FOODRET12m	Trend	MRET12	FOODPB	FOODSIZE	DP12	INF12
CP	1							
FOODRET12m	0.048	1						
Trend	0.016	0.06	1					
MRET12	0.044	0.162	-0.025	1				
FOODPB	-0.005	-0.139	0.059	-0.126	1			
FOODSIZE	0.019	-0.066	-0.114	0.000	0.17	1		
DP12	-0.002	0.076	-0.063	0.067	-0.188	0.011	1	
INF12	-0.043	0.178	0.137	0.256	0.045	-0.216	-0.047	1

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## 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

- ▶ Use net income scaled by lagged total assets as proxy for profitability
- ▶ Quintile portfolios are sorted on lagged PDSI time trend. Middle three portfolios grouped together by equal weighting their profitability changes
- ▶ (t, t+1) is the change of profitability over the 1-year period following portfolio formation date. (t, t+1) and (t, t+2) 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	-0.3458** (-2.28)	-0.1519* (-1.82)	-0.7443* (-1.74)
FOODPB		-0.2539 (-1.51)	0.6180 (1.36)
FOODRET12		0.0056 (0.88)	0.0296 (1.23)
DP			0.0219 (0.25)
MRET12			-0.0270 (-0.82)
INF12			-6.4586*** (-3.70)

- ▶ 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	-0.2075*** (-2.76)	-0.1653* (-1.99)	-0.8896** (-2.37)
FOODPB		-0.2504 (-1.56)	0.6237 (1.37)
FOODRET12		0.0040 (0.50)	0.0269 (1.07)
DP			0.0242 (0.32)
MRET12			-0.0289 (-0.88)
INF12			-7.1970*** (-3.82)

- ▶ 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

<b>Panel A: 1-year holding horizon</b>				
	Excess Return	CAPM	Carhart 4-factor	Currency Factors
Lowest Quintile	0.33	0.23	0.19	-0.19
Middle	0.75	0.63	0.68	0.03
Highest Quintile	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.

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### Panel B: 2-year holding horizon

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	Excess Return	CAPM	Carhart 4-factor	Currency Factors
Lowest Quintile	0.30	0.19	0.17	-0.23
Middle	0.71	0.59	0.64	-0.01
Highest Quintile	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

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### Panel C: 3-year holding horizon

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	Excess Return	CAPM	Carhart 4-factor	Currency Factors
Lowest Quintile	0.28	0.18	0.15	-0.24
Middle	0.68	0.56	0.60	-0.05
Highest Quintile	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

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## Returns to Portfolios Sorted on PDSI Time Trend For Other Industries

Industry	4-factor alpha	t-stat
<b>Food &amp; Beverage</b>	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 at the Industry Classification Benchmark supersector level



## Calibration of Change in Net Income with Change of Price

- ▶ During the 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	-7.0517*** (-3.59)	-2.0315* (-1.84)	-5.3988*** (-2.76)
FOODPB		-3.9076*** (-3.44)	-1.4628 (-1.50)
FOODRET12		0.0010 (0.01)	-0.1394 (-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

## FOOD Return on PDSI Time Trend, Sub-Sample Analysis

	1985–1999	2000–2014
Low Trend	-5.2835 (-1.05)	-5.5305** (-2.95)
FOODPB	-1.1401 (-0.48)	-1.8316 (-0.89)
FOODRET12	-0.2331 (-0.62)	-0.0324 (-0.29)
DP	0.2377 (0.75)	2.5128*** (3.79)
MRET12	-0.0721 (-1.11)	0.0359 (0.62)
INF12	4.5318 (1.45)	0.3506 (0.54)

- ▶ Split the whole sample into two sub-samples, 1985 to 1999 and 2000 to 2014

## FOOD Return on Initial PDSI Time Trend at 1984 end

	(1)	(2)	(3)
Low Trend	-3.9439 (-1.44)	-2.7447** (-2.30)	-3.3472 (-1.54)
FOODPB		-4.2718*** (-3.44)	-1.8746* (-1.74)
FOODRET12		-0.0063 (-0.07)	-0.1454 (-0.89)
DP			1.3949** (2.45)
MRET12			0.0024 (0.07)
INF12			2.6246 (1.48)

- ▶ (Initial) "Low Trend" is a dummy variable equal to 1 for countries in the lowest quintile based on its estimated PDSI time trend at the end of 1984

## Change of FOOD Profitability on PDSI Trend, Robustness

	PDSI Time Trend Estimated with 2 Lags of PDSI		PDSI Time Trend Estimated with 3 Lags of PDSI	
	(1)	(2)	(3)	(4)
Low Trend	-0.3587** (-2.50)	-0.7399* (-1.73)	-0.3513** (-2.38)	-0.6946 (-1.55)
FOODPB		0.5929 (1.27)		0.5879 (1.25)
FOODRET12		0.0297 (1.23)		0.0297 (1.23)
DP		0.0179 (0.20)		0.0167 (0.19)
MRET12		-0.0269 (-0.81)		-0.0264 (-0.79)
INF12		-6.0739*** (-3.41)		-5.9477*** (-3.40)

- ▶ Columns (1)–(2), PDSI time trend estimated with 2 lags of PDSI ( $PDSI_{i,t-1}$  and  $PDSI_{i,t-2}$ ). Columns (3)–(4), estimated with 3 lags ( $PDSI_{i,t-1}$  to  $PDSI_{i,t-3}$ )
- ▶ Dependent variable is future 1-year change in FOOD profitability. "Low Trend" the same dummy variable as before for countries at the end of each year

## FOOD Return on PDSI Trend, Robustness

	PDSI Time Trend Estimated with 2 Lags of PDSI		PDSI Time Trend Estimated with 3 Lags of PDSI	
	(1)	(2)	(3)	(4)
Low Trend	-5.5340*	-5.1296**	-6.8162***	-4.2790**
	(-2.03)	(-2.50)	(-3.68)	(-2.53)
FOODPB		-1.4314		-1.8408*
		(-1.47)		(-1.83)
FOODRET12		-0.1395		-0.1371
		(-0.85)		(-0.84)
DP		1.2903**		1.3065**
		(2.18)		(2.20)
MRET12		-0.0227		-0.0142
		(-0.65)		(-0.42)
INF12		2.5926		2.5678
		(1.44)		(1.42)

- ▶ Columns (1)–(2), PDSI time trend estimated with 2 lags of PDSI ( $PDSI_{i,t-1}$  and  $PDSI_{i,t-2}$ ). Columns (3)–(4), estimated with 3 lags ( $PDSI_{i,t-1}$  to  $PDSI_{i,t-3}$ )
- ▶ Dependent variable is non-overlapping food return over future 12 months. "Low Trend" the same dummy variable as before for countries 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	1.31	0.49	1.16
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 5

## Returns to Portfolios Sorted on Standardized PDSI36m

Portfolio	Excess Return	t-stat	Carhart 4 factors	t-stat	Currency Factors	t-stat
Lowest Quintile	0.38	1.31	0.27	1.04	-0.14	-0.57
Middle	0.71	3.03	0.59	3.14	0.17	0.89
Highest Quintile	1.15	3.87	1.10	4.28	0.45	1.86
High - Low	0.77	2.74	0.83	2.87	0.59	2.25

- ▶ Standardized PDSI36m is PDSI36m 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



# 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