

Climate Risks and Market Efficiency

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Abstract

We investigate the efficiency of the stock market with respect to risks brought on or exacerbated by climate change. We focus on drought, the most damaging natural disaster for crops and food-company cash flows. We show that prolonged drought in a country, measured by the Palmer Drought Severity Index (PDSI) from climate studies, forecasts poor stock returns for food companies in that country. A long-short portfolio of global food stocks based on PDSI generates a 9.2% annualized return. Our findings support regulatory concerns of markets underreacting to climate risks and calls for disclosing such corporate exposures.

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1 Introduction

We investigate the extent to which stock markets are efficient with respect to climate risks that are brought on or exacerbated by climate change. This question is important for at least three reasons. First, efficient capital markets can play an important role in helping households manage the risks of climate change. Such risks include a corporation's exposure to carbon assets or inputs, which might be affected by future carbon prices or taxes. This so-called stranded asset issue has attracted the most discussion in regulatory and market circles at this point.¹ But climate risks need not be so narrowly confined to carbon exposure. Vulnerability of corporations' production processes to natural disasters such as prolonged drought, which is likely to be amplified by climate change (Trenberth, Dai, van der Schrier, Jones, Barichivich, Briffa, and Sheffield (2014)) and the focus of our paper, is also important and can impose significant damage to corporate profits. Regardless of the risks, to the extent stock markets can appropriately price the exposures of corporations, losses will be ameliorated by an appropriate risk premium.

Second, regulators worried about the effect of climate change on the stability of financial markets are proposing a variety of both voluntary and mandatory disclosure requirements for corporations regarding their climate risk exposures.² Most notably, Mark Carney the head of the Bank of England has pointed toward the risks of climate change for financial stability and the role of disclosures (Carney (2015)). One impetus for this push is that markets might be underreacting to such risks because they might not be salient and disclosures can help the market better incorporate such concerns into pricing. A study of climate risks and market efficiency can hence characterize the nature of the potential inefficiencies, which might help shape regulatory responses.

Third, such efficient market studies, which would naturally focus on excess stock return pre-

¹See, e.g., "The elephant in the atmosphere," *Economist* July 19th, 2014.

²Examples of the more prominent voluntary disclosure initiatives include the Carbon Standards Disclosure Board, Integrated Reporting, the Carbon Disclosure Project, and the UN Principles for Responsible Investment.

dictability by climate risk variables, can be useful for practitioners interested in the construction of quantitative portfolio models to help manage such risks (Shiller (1994)). Climate risk variables can be quantified and have been used successfully in the pricing of weather derivatives.³ However, the broader question of the extent to which information on such risks is appropriately discounted in stock markets has not received much attention to date.

We tackle this broad question by focusing on the efficiency to which stock prices respond to information about drought. Our focus on drought has a few different motivations. To begin with, studies on climate change and crop production typically find that, among the natural disasters that might be amplified by climate change, including drought, heat waves, floods, cold spells, drought is considered one of the most devastating for economic production. A recent study (Lesk, Rowhani, and Ramankutty (2016)) looks at about 2,800 weather disasters along with data on 16 different cereals, including oats, barley, rye and maize, grown in 177 countries. They found that droughts cut a country's crop production by ten percent, and heat waves by nine percent, but that floods and cold spells had no effects on agricultural production levels.⁴

Our dependent variable of interest is the return of the FOOD industry portfolio from the Fama and French (1997) 17 industry classification, where FOOD combines food processing and agricultural companies. We focus on this aggregated industry portfolio as opposed to the finer industry classifications which separate FOOD into smaller components because drought is likely to have a direct impact on the profits of both food processing and agricultural companies. To begin with, a number of water engineering studies find that the food industry is arguably the most reliant on water and hence the most sensitive to drought risk (Blackhurst, Hendrickson, and Vidal (2010)).⁵ Moreover, there are increasing reports of dramatic short-falls in earnings

³See, e.g., Campbell and Diebold (2011).

⁴This is distinct from whether a warming climate is good or bad for crop yields (Mendelsohn, Nordhaus, and Shaw (1994)).

⁵The other major industry perhaps comparable to FOOD in terms of water use is the power industry, but utilities are regulated and their profitability is largely unaffected by drought. The only other industry that also consumes significant water in its production process is the automotive industry but its reliance on water is much less than that of FOOD. So we focus on FOOD in this paper.

and compressed profitability ratios or margins for even very large agribusinesses such as Cargill, Tyson Chicken, and Campbell Soup due to drought.⁶ For instance, Tyson Chicken, a large multinational food processor, suffered steep profit drops due to the 2012 droughts in the main US agricultural states, including California.⁷ Grain price is the main input cost for raising chickens. The higher grain prices squeezed the profit margins of even a large food processor. And extreme reductions of output can also hurt food businesses relying on turnover as well as margins. Drought also creates water shortages which impact agricultural companies. While some of these cost increases can be temporarily passed onto consumers or farmers might sell off some types of crops or livestock, prolonged drought ultimately also severely impacts agriculture as well.

Our independent variable of interest is the Palmer Drought Severity Index (PDSI), a widely used metric in climate studies (Palmer (1965)). PDSI combines information such as temperature and the amount of moisture in the soil to create an index that does an accurate job of measuring drought intensity. Less positive values of PDSI are associated with more drought-like conditions. While not perfect, it is by far the most widely used in climate studies and the most readily available (Alley (1984)). This data is available in the US by state going back to the 1890s. Globally, it is available at the country level and going back to the 1870. PDSI is available at a monthly frequency and hence we can for each month calculate a moving average of PDSI from a horizon of a few months to years back.

We can then forecast the stock returns of food and agricultural companies using this moving-average PDSI variable, which captures both the intensity and duration of the drought. To the extent markets are efficient, we expect zero excess return forecastability on our moving-average PDSI. If markets are underreacting to these risks, we expect that the more negative the PDSI is, the more negative the stock returns are in the future.

⁶See "Feeding Ourselves Thirsty: How the Food Sector is Managing Global Water Risks", *A Ceres Report*, May 2015.

⁷see, e.g., "Meat Stocks Fall Tyson 8% As Drought Hits Earnings", *Investor's Business Daily* August 6, 2012.

We begin with a study of the US, where we have the most extensive data. We focus on a monthly weighted-average (using cropland areas) of PDSI across the states (PDSIWA). Our focus is on the top 10 agricultural producing states (based on crop receipts). We also consider other measures including using all states in the US in the robustness checks. Our main predictor variable will be a moving average of this series, averaged over horizons of anywhere from 12 months to 36 months (PDSIWA12m to PDSIWA36m). Droughts are considered economically worrisome should the PDSI be elevated for a prolonged period. For short durations, drought has a negligible effect as production can adjust. It might even be helpful depending on when it occurs (before or after a harvest). But long periods of drought, running into years such as what is happening in California, unambiguously has negative consequences.

As our baseline, we focus on a 36-month moving average (PDSIWA36m). We use this variable to then forecast the returns of the FOOD portfolio net of the risk-free rate. Our dependent variable is the return of FOOD net of the risk-free rate over the next 12 months. We want to look at the industry returns to FOOD while controlling for returns to the market. That is, our hypothesis is that drought predicts returns due to news about food industry specific cashflows. But we cannot simply net the market portfolio returns from FOOD since the FOOD sector is a sizeable portion of the market.

As such, we extract the food industry specific returns in two ways. The first is that we control in our predictive regressions for a host of variables that are known to predict aggregate market returns, including lagged values of inflation (INF), aggregate market returns (MRET), dividend yield (D/P), net equity issuance (NTIS), default spreads (DSPR), and term spreads (TSPR). The second is that we can calculate the market portfolio net of FOOD stocks and then subtract from the FOOD returns the returns of the market portfolio purged of the FOOD sector. We will focus on the first method, though both sets of analyses yield similar results.

To start with, in our sample from 1927 to 2014, the standard market predictor variables all come in with the expected signs from the literature in terms of predicting the next 12 month

returns of FOOD since FOOD returns contain an important market return component. We then also control for past 12-month returns of the FOOD portfolio and the book-to-market ratio of the FOOD portfolio. The idea is that this adjusts for potential momentum and book-to-market effects unique to the industry portfolio. With these conservative controls and using non-overlapping 12 month returns, the coefficient on the lagged 36-month moving-average of PDSI (PDSIWA36m) is 2 with a t-statistic of 2.53. The t-statistic is Newey and West (1986) adjusted with 36 lags. A one standard deviation drop in PDSIWA36m is associated with a lower future return of FOOD, by around 2.5% over the next twelve months. The mean excess FOOD portfolio return over 12 months is 7.16% with a standard deviation of 17.45%. Hence the implied economic effect is nearly 35% of the mean food portfolio return and 15% of its standard deviation.

We then consider a number of extensions and robustness checks of our baseline specification. To begin with, using non-overlapping returns, we also consider short-horizon return predictability, including the next 1-month FOOD return, next 3-month FOOD and next 6-month FOOD return, and find similar results. The economic magnitudes and statistical significance are in line with the 12-month return results. One important concern is that the t-statistics of our predictability regressions are inflated due to persistent predictor variables since our PDSIWA36m is highly persistent (close to a random walk). To deal with this concern, we implement the Campbell and Yogo (2006) test. The residuals of the AR(1) regression of PDSIWA36m at the monthly frequency with the return residuals from our monthly predictive regression of FOOD is only -0.001, indicating that our tests of statistical significance are not biased.

We find that the predictability of FOOD returns by drought rises the more prolonged is the drought. We also find other measures of PDSI such as using all 48 states as opposed to the top 10 states have predictive power for food returns. When we use the second approach to calculate FOOD returns in excess of the market, by subtracting the returns of the market portfolio net of the FOOD sector from our FOOD returns (i.e. FOODXMRET), our estimate in front of our

coefficient of interest is 1.23 with a t-statistic of 3.01. A one standard deviation increase in PDSIWA36m leads to a 1.55% higher return over the next 12 months for FOODXMRET. The mean of FOODXMRET is 1% with a standard deviation of 11.75%. As such, the economic significance is comparable to our first method.

We have focused on the returns of the FOOD industry since it is the most directly linked to drought and our prior is that drought ought have less explanatory power other industries. We show that this is indeed the case. Moreover, the PDSI index strongly predicts changes in FOOD industry profitability ratios, as measured by industry net income over assets, confirming our hypothesis that the industry return predictability is due to the market underreacting to this link between drought and industry profitability.⁸ The one drawback of this analysis is our sample on profitability only goes back to the 1950s.

Finally, we study the effect of drought on expected returns in an international sample of countries excluding the US. We consider a sample of 30 countries. However, the time series of these countries are much shorter than that of the US. The earliest start date is 1975 and much of our sample only begins in the early 1990s. As such, we pool together all the countries to run our regressions. Consistent with the US results, the coefficient in front of our 36 month moving average drought measure for our international sample is 3.61 for the 12 month future returns with a t-statistic of 2.18. Thus the economic and statistical significance for our international sample are similar to those of the US results obtained from the long time series. The consistency of these results across countries and also across short and long horizons is comforting.

One benefit of exploiting the international cross-section is that we can construct an alternative measure of the excess return predictability through creating portfolio strategies that condition on the PDSI information. For instance, a strategy that longs the food industry portfolios of countries with high PDSI and short those with low PDSI in any given month and holding for one year generates an excess return of 0.77% per month with a t-statistic of 2.74.

⁸PDSI does not predict any other industry profitability ratios except for the automotive industry but these results are more sensitive to specifications than FOOD.

The Sharpe Ratio is 0.50. The results are similar whether we adjust the return spread using global Sharpe (1964) CAPM, Fama and French (1993) three factor or Carhart (1997) four factor model as our long/short portfolio has little exposure to these common factors.

Regardless of the method, our interpretation of these findings is that the market underreacts to the information in prolonged drought for the profits of the FOOD industry. Our findings are similar in spirit to the recent literature on attention and return predictability (see e.g., Hong, Torous, and Valkanov (2007), DellaVigna and Pollet (2007), Cohen and Frazzini (2008)), whereby the market underreacts to many types of value relevant information such as industry news, demographic shifts, and upstream-downstream relationships. Even for these types of obviously relevant news, the market can be inattentive. Our analysis points to a similar underreaction to information on climate risks. In such a world, disclosures properly constructed can improve market efficiency (Hirshleifer and Teoh (2003)), supporting recent proposals by central banks and regulators on this issue.

There is a large literature on the economic analysis of how to design government policies to deal with climate change (see, e.g., Stern (2007), Nordhaus (1994)), be it through emissions trading (Montgomery (1972)) or taxes (Golosov, Hassler, Krusell, and Tsyvinski (2014)). In contrast, our analysis highlights the role of markets in potentially mitigating the risks brought on by or exacerbated by climate change. Understanding the role of financial markets in pricing climate risks is a natural one, though work is limited at this point with some notable exceptions. Bansal, Kiku, and Ochoa (2014) argue that long-run climate risks as captured by temperature are priced into the market. Daniel, Litterman, and Wagner (2015) show stock markets might help guide government policies assuming markets efficiently incorporate such climate risks. Our analysis suggests that such climate risk information, at least when it comes to natural disasters, are not efficiently priced.

Our paper proceeds as follows. We present our data in Section 2. We discuss the PDSI metric in Section 3. In Section 4, we present the US results. In Section 5, we present the

international results. We conclude in Section 6.

2 Data, Variables and Summary Statistics

2.1 US Drought Measures

All of our US data start in 1927 and end in 2014. Our PDSI data for the US comes from the National Centers for Environmental Information (NCEI) of the US National Oceanic and Atmospheric Administration (NOAA). The PDSI is updated monthly on the NOAA’s website, and the index value extends back to January 1895. The index is a measurement of drought intensity based on a supply-and-demand model of soil moisture developed by Palmer (1965). The index takes into account not only temperature and the amount of moisture in the soil, but also hard-to-calibrate factors such as evapotranspiration and recharge rates. It is a widely used metric in climate studies. The index grades drought and moisture conditions in the following scale: -4 and below is extreme drought, -3.9 to -3 is severe drought, -2.9 to -2 is moderate drought, -1.9 to 1.9 is mid-range (normal), 2 to 2.9 is moderately moist, 3 to 3.9 is very moist, 4 and above is extremely moist. The extreme values for PDSI are -10 and 10.

We obtain the monthly PDSI data of all 48 contiguous states in the US (excluding Alaska and Hawaii because there is no data) from January 1927 to December 2014 as well as the aggregated US drought measure produced by US NOAA (PDSIUSA). PDSIUSA is essentially a land-area weighted average of the PDSI values from all climate divisions in the US. This is not the ideal measure for us since we are interested in the effects of drought on food and agricultural companies and as such we will focus on states that have a substantial farming sector. Nonetheless, it is instructive to start by plotting out this standard NOAA measure.

Figure 1 illustrates the historical evolution of this drought measure from January 1927 to December 2014, with its value shown on the vertical axis. The PDSIUSA measure identifies some of the most recognizable droughts in the US history. For example, we can see the infamous “Dust

Bowl” period of prolonged droughts in the 1930s, and an extended period of severe droughts in the 1950s, with the PDSI value falling frequently below -2 and even breaking -8. From the 1960s to the 1980s, the US experienced several spells of relatively shorter yet significant droughts. Since the turn of the 21st century, the US has been bombarded by various droughts that include the current ongoing drought in California. This might suggest that the climate risk due to global warming has intensified, as the droughts in the 1930s and 1950s could be (at least) partly attributed to bad soil management and exploitative farming techniques.

To go a bit further, we present the geography of droughts in the US history by showing the PDSI values of two top food-producing state, California and Texas. Figure 2 and 3 illustrate California’s and Texas’ historical PDSI values respectively. We observe that the two states coincide well in certain spells of droughts historically, such as the Dust Bowl in the 1930s and the drought around 2008. However, the two states can be very asynchronous in other periods of severe droughts. For instance, Texas had a persistent and severe drought between 1950 and 1957 but California had little, whereas California has been experiencing a prolonged, ongoing drought since 2013 but Texas has not.

Because not every state in the US has significant croplands or an agricultural sector, we construct our own aggregated measures of drought for the US. The first one, PDSIWA, is the weighted average of the PDSI values from the top 10 food-producing states (in terms of gross cash income of the state’s farm sector), using cropland area as weight. Data for both the cropland area and the gross cash income of the farm sector in each state are obtainable from the US Department of Agriculture. The top 10 food-producing states are (in alphabetic order): California, Illinois, Indiana, Iowa, Kansas, Minnesota, North Carolina, Nebraska, Texas, Wisconsin. This is our main drought measure.

Our second aggregate measure (PDSIASWA) is the weighted average of the PDSI values from all 48 contiguous states based on cropland area. We focus on the top 10 food producing states but a number of states have some croplands, and so we also consider this measure. Our

third aggregate measure is PDSIASCWA which is simply the weighted average PDSI of the 48 states using gross cash income of the farm sector as weights.

Since droughts that last for a few months are unlikely to do any harm to the food industry (and under certain circumstances might even be helpful depending on whether it occurs before or after a harvest), we consider a moving average of these monthly drought measures, where the average is over years. As we discussed in the Introduction, prolonged droughts that last years are likely to substantially impair food industry cashflows and hence their stock prices. The idea is that by shortening or lengthening the window over which we do the average, we pick up more prolonged periods of drought. For our main baseline measure PDSIWA, using the top 10 states, we consider moving averages from 12 months to 36 months (e.g. PDSIWA12m to PDSIWA36m). For our other three drought measures, we will just consider a 36 month moving average. In theory, we could average over much longer periods of time. The trade-off is that we then lose time series variation in our drought measure. As such, we consider 36 month (a 3 year drought) as a reasonable length to focus on and assess the sensitivity of our findings to differing lengths.

Panel A of Table 1 shows the summary statistics for our various drought measures. Our main drought measure PDSIWA36m has a mean of 0.17 and a standard deviation of 1.26. Moreover, the four drought measures are all positively correlated, as demonstrated in Panel D of Table 1. The PDSIUSA36m measure is less correlated not surprisingly with our other three measures since it weighs by land mass as opposed to cropland. Nonetheless, the correlation of PDSIUSA36m with PDSIWA36m is 0.88. As such we expect our baseline measure to be a better predictor of food stock returns than the PDSIUSA36m measure but this standard NOAA measure ought to still have some information about food stock returns.

2.2 US Stock Market Data

Our second set of data comes from Kenneth French's website.⁹ It contains the monthly value-weighted returns for the Fama-French 17 industry portfolios from January 1927 to December 2014. The 17 industries are: (1) Food, (2) Mining and Minerals, (3) Oil and Petroleum Products, (4) Textiles, Apparel and Footware, (5) Consumer Durables, (6) Chemicals, (7) Drugs, Soap, Perfumes, Tobacco, (8) Construction and Construction Materials, (9) Steel Works, (10) Fabricated Products, (11) Machinery and Business Equipment, (12) Automobiles, (13) Transportation, (14) Utilities, (15) Retail Stores, (16) Banks, Insurance Companies and Other Financials, (17) Other. The FOOD industry includes agriculture firms, food products and food processing firms, candy and soda-producing firms, beer and liquor-producing firms, as well as wholesale firms that are related to all of these.

We take the raw continuously compounded monthly industry returns and net them off the one-month T-bill return to obtain the monthly excess returns for all industries. We denote the food industry excess return by FOODRET. We then take the FOODRET at 1-month, 3-month, 6-month, and 12-month frequencies. Panel B of Table 1 shows the summary statistics for FOODRET. Our baseline dependent variable of interest, FOODRET12m, has a mean of 7.16% and a standard deviation of 17.45%.

In addition to FOODRET12m, we create a FOOD industry return that nets the market portfolio. The problem is that the FOOD industry is also a big part of the market. As such, we create a market portfolio excluding the food stocks and then subtract the returns of this alternate market portfolio from the FOOD industry returns. We call this variable FOODXMRET12m. It has a mean of 1% and a standard deviation of 11.75%.

Our second data set also has the value-weighted average book-to-market ratio for each of the industries observed at annual frequency. We take the log value for all the industry book-to-market ratios, and we denote this value for the food industry by FOODBM. Moreover, it has

⁹http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

the monthly market excess returns (the CRSP value-weighted market portfolio excess return over the Treasury-bill), and we denote this variable by MRET.

Our third set of data comes from Amit Goyal's website.¹⁰ It contains the monthly data for all other market predictor variables that we will use. It includes the following variables: the inflation rate (INF), the log value of the dividend-price ratio of the S&P 500 index (DP), the volatility of the S&P 500 index (MVOL), the net equity expansion of the NYSE stocks (NTIS), the difference between BAA and AAA-rated corporate bond yields (DSPR), and the difference between the long term yield on government bonds and the Treasury-bill (TSPR). Panel C of Table 1 provides the summary statistics for all of our predictor variables (annualized and hence the appending of 12 (denoting 12-month) to the variable names) as well MRET12 and FOODBM12. We can see that the summary statistics of our variables are consistent with those in the literature. For instance, our market excess return MRET12 has a mean of 6% and a standard deviation of 20% (see, e.g., Fama and French (2015)). Moreover, our annual inflation is 2.94% that is in line with the long-run inflation rate in the US.

In Figure 4, we plot the time series of our independent variable of interest (PDSIWA36m) along with one of our dependent variable of interest (the future 12-month return of the food industry net of the market return, i.e. FOODXMRET12m). To the extent that the market is not efficiently pricing in the information about prolonged droughts, we expect a positive correlation between these two time series. This is indeed what we see. We have marked some of the main droughts in US history. Prolonged drought episodes are typically periods when future returns to the food portfolio is low. Similarly, periods when there is plentiful water (i.e. positive values of PDSI) are associated with higher than average returns to the food industry portfolio. As we will show in various ways below, the relationship between these two time series is positive and statistically significant.

¹⁰<http://www.hec.unil.ch/agoyal/docs/PredictorData2014.xlsx>

2.3 International Drought Measures

Our data for the global Palmer Drought Severity index comes from Dai, Trenberth, and Qian (2004). The data consists of the monthly PDSI over global land areas computed using observed or model monthly surface air temperature and precipitation. The global PDSI dataset is structured in terms of longitude and latitude coordinates and we extract each country's PDSI based on that country's geographic coordinates. The sample period of global PDSI is from January 1870 to December 2014. As argued by Dai, Trenberth, and Qian (2004), the global land areas in either very dry or very wet conditions have increased from 20% to 38% since 1972, with surface warming as the primary cause after the mid-1980s. These results provide observational evidence for the increasing risk of droughts as anthropogenic global warming progresses and produces both increased temperatures and increased drying.

In addition, we also present the evolution of droughts in a number of countries from our international sample. Figure 5 plots the time series of monthly PDSI values for several countries, including Australia, China, UK, Russia and Canada. The sample starts from 1927 and ends in 2014. We also identify some of the most severe drought episodes in the history, which correspond closely to very negative values of PDSI in the data. For example, the Millennium drought in Australia started from 1997 and continued for more than 10 years, which is recognized as the worst on record since settlement in Australia.

One key takeaway from all these drought graphs, both in the US and globally, is that there is no trend in these PDSI series. Hence, we do not need to worry about spurious correlations caused by time trends in our sample. This is not to say that drought could not be increasing over time as argued by some scientists. But for the purposes of our empirical analysis, we are on safe ground in assuming a stationary (non-trending) process for PDSI when implementing our time series regressions.

2.4 International Stock Market Data

We obtain firm-level stock returns and accounting variables for a broad cross section of countries (except for the U.S.) from Datastream and Worldscope, respectively. The sample includes live as well as dead stocks, ensuring that the data are free of survivorship bias. We compute the stock returns in local currency using the return index (which includes dividends) supplied by Datastream and convert them to U.S. dollar returns using the conversion function built into Datastream. In some of our tests, we also use price-to-book ratio which is directly available from Worldscope database. Inflation rate for international countries is from World Bank database.

We apply the following sequence of filters that are derived from the extensive data investigations by Ince and Porter (2006), Griffin, Kelly, and Nardari (2010) and Hou, Karolyi, and Kho (2011) as follows. First, we require that firms selected for each country are domestically incorporated based on their home country information (GEOGC). A single exchange with the largest number of listed stocks is chosen for most countries, whereas multiple exchanges are used for China (Shanghai and Shenzhen), Japan (Tokyo and Osaka), and the U.S. (NYSE, Amex, and Nasdaq). We eliminate non-common stocks such as preferred stocks, warrants, REITs, and ADRs. A cross-listed stock is included only in its home country sample. If a stock has multiple share classes, only the primary class is included. For example, we include only A-shares in the Chinese stock market and only bearer-shares in the Swiss stock market.

To filter out suspicious stock returns, we set returns to missing for stocks that rises by 300% or more within a month and drops by 50% or more in the following month (or falls and subsequently rises). We also treat returns as missing for stocks that rise by more than 1,000% within a month. Finally, in each month for each country, we winsorize returns at the 1st and the 99th percentiles, to reduce the impact of outliers on our results (McLean, Pontiff, and Watanabe (2009)). Datastream classifies industries according to Industrial Classification

Benchmark (ICB). The food portfolio includes stocks in the food & beverage supersector¹¹. Food portfolio returns are individual stock returns weighted by lagged market capitalization. In addition, to meaningfully identify the drought impact in our international sample, we further exclude countries with less than 10 stocks in the food portfolio in its entire time series. The final sample includes 30 countries, among which 15 are developed countries and 15 are developing countries.

Table 2 Panel A reports the summary statistics of our international sample. The average number of stocks in the food industry varies considerably across countries, from 7 in Finland to 108 in India. We also report the median firm market capitalization in the food industry within each country as of the end of 2013 in millions of U.S. dollars, as well as the mean and standard deviation of the monthly PDSI values for each country.

As we can also see from Panel A, the time series of stock returns for international countries are much shorter than for the US. As a result, we cannot conduct an individual time series exercise for each country as we do for the US. Instead, we will pool together all the international monthly observations and run a pooled regression. We control for country fixed effect to isolate the time series return predictability of lagged PDSI from the cross-country effect. Panel B reports the summary statistics for our pooled sample of international countries. Our independent variable of interest is a 36 month moving average of the monthly PDSI in each country (PDSI36). Note that these PDSI values are reported by month and by country. We do not, unlike for the US, have finer data with which to aggregate the measure to take into account cropland. The mean PDSI36 is -0.33 with a standard deviation of 1.49.

We also do not have as many market predictor variables for the international sample as we do for the US sample. The market predictor variables we have for the international sample include the lagged 12-month returns of the market (MRET12), the lagged inflation rate of

¹¹ICB Supersector Level classifies industries as follows: Oil & Gas, Chemicals, Basic Resources, Construction & Materials, Industrial Goods & Services, Automobiles & Parts, Food & Beverage, Personal & Household Goods, Health Care, Retail, Media, Travel & Leisure, Telecommunications, Utilities, Banks, Insurance, Real Estate, Financial Services, Equity/Non-Equity Investment Instruments, and Technology.

the country (INF12), the dividend-to-price ratio of country market index (DP12) and market volatility (MVOL12). Food industry-specific controls include the price-to-book ratio of the food industry stocks (FOODPB12) and the 12-month food industry return (FOODRET12m). The mean annual market return is 10.25% with a standard deviation of 40.78%. The mean annual inflation rate is 2.63%, annual dividend-to-price ratio is 3.12% and the mean annual market volatility is 23.12%. The mean price-to-book ratio for the food stocks is 2.58.

Finally, we report the summary statistics for the international FOOD industry portfolios which are net of the risk-free rate. The mean of the 12-month return is 12.86% with a standard deviation of 41.30%. Notice that both the mean and the standard deviation of the FOODRET12m are larger than in the US. International food stocks have done better over this sample and the wider standard deviation also reflects that we are pooling together all observations.

3 US Results

To consider the impact of droughts on food and agricultural companies, and forecast their stock returns using our drought measures, we begin with a study of the US where we have the most extensive data.

3.1 Food Portfolio Returns

3.1.1 Baseline Specification

In Table 3, we focus on the 36-month moving average of the PDSIWA using the top 10 food producing states (PDSIWA36m) as our baseline drought measure. We then use this variable to forecast FOODRET12m, the excess returns of the FOOD industry portfolio (net of the risk-free rate) FOODRET over the next 12 months. Our sample period is from 1927 to 2014. In column (1), we report the coefficients using the traditional market predictor variables, including the

lagged 12-month aggregate market return MRET (see, e.g., Poterba and Summers (1988)), the inflation rate INF (see, e.g., Fama and Schwert (1977)), the log value of the dividend-price ratio of the aggregate market DP (see, e.g., Campbell and Shiller (1988)), the volatility of the aggregate market MVOL (see, e.g., French, Schwert, and Stambaugh (1987)), the net equity expansion of the aggregate market NTIS (see, e.g., Baker and Wurgler (2000)), a corporate bond spread (DSPR), and a treasury yield spread TSPR (Fama and French (1989)).¹² The idea is that the FOOD industry portfolio contains a systematic market component and these predictor variables ought to forecast FOOD with the same sign that they forecast the market returns.

Indeed, these predictor variables come in with the expected signs, though their statistical significance varies depending on the sample period. The coefficient on MRET12 is negative, consistent with long-horizon mean reversion. The coefficient on INF12 is positive. A higher dividend-price ratio forecasts higher returns. Over this sample period, this variable is highly statistically significant. Lagged market volatility attracts a negative sign. High net equity issuance forecasts low future returns. High default spreads and term spreads forecast high future market returns. The R^2 of this time series regression is 22% with 85 yearly observations. As such, we believe that this expected return model for the market does an adequate job of explaining the systematic component of FOOD industry returns.

In column (2), we add in two FOOD industry specific variables in the form of the lagged past 12-month FOOD industry returns (FOODRET12m) and the book-to-market ratio of the FOOD industry portfolio (FOOBM12). These FOOD industry specific return predictors are motivated by momentum or positive serial correlation in industry portfolios (Moskowitz and Grinblatt (1999), Hong, Torous, and Valkanov (2007)) and the potential conditioning information in the cost of equity by industries (Fama and French (1997)). Both variables come in with the expected signs. They are not individually significant in this sample period but increase the R^2 from 22% in column (1) to 24% in column (2).

¹²All of these market predictor variables have a suffix of 12 to denote they are annualized values over the past 12 months.

In column (3), we then add in our variable of interest PDSIWA36m and find that it has significant incremental forecasting power for the future returns of the food portfolio. The coefficient estimate of PDSIWA36m is 2 with a t -statistic of 2.5, which is significant at the 5% statistical significance level. It increases the R^2 from 24% in column (2) to 26% in column (3). Moreover, notice that the coefficients in front of the previous market and industry predictor variables from columns (1) and (2) are largely unchanged. This is to be expected from our discussion on Panel D of Table 1 regarding the contemporaneous correlations of the PDSIWA36m with the standard market and industry predictor variables. Our variable of interest is not significantly correlated with these predictors. As a result, adding our variable of interest has little effect on the coefficients in columns (1) and (2). Hence we can be assured that our drought variable is not picking up the traditional market predictors nor is it priced into the book-to-market ratio of the FOOD industry. If the information in drought were priced in, we might expect it to be captured by the FOOD past returns and book-to-market ratio in column (2).

To the extent markets are efficient, we would expect zero excess return forecastability on the moving average of PDSIWA for the food portfolio. However, our baseline result of strong forecastability suggests that markets are under-reacting to climate risks from droughts. Moreover, the sign on the coefficient of interest suggests that this is not a risk premium mechanism at work. If it were risk, we would expect that more intense drought results in higher as opposed to lower expected returns. Moreover, we might expect that if markets were efficient in pricing drought, the information in drought would be captured by the FOOD industry book-to-market ratio introduced in column (2).

The implied economic significance of our PDSI variable is large. It means that if the average weighted PDSI value of the top 10 food-producing states over the previous 36 months falls by 1 standard deviation (about 1.26 from Table 1), the average excess return of the food industry portfolio over the risk-free rate in the next 12 months (FOODRET12m) will decrease by about 2.5%. From Table 1, the mean FOODRET12m is 7.16% with a standard deviation of 17.45%.

Thus the implied economic effect is about 35% of the mean of the food portfolio return and about 15% of the standard deviation of FOODRET12m, which are both economically significant results.

Another way to gauge the economic significance of our drought variable is to compare it to the predictive power of the traditional market predictors. In column (3), the two most powerful predictors are the net equity issuance (NTIS12) and term spread (TSPR12). A one standard deviation increase in net equity issuance forecasts lower FOOD returns by 5.95% over the next 12 months. The corresponding magnitude for treasury spread is 3.9%. Therefore, our drought effect is about 40% of that of the net equity issuance variable and 60% of that of the treasury spread variable.

To visualize the regression results in Table 3, we produce a scatterplot in Figure 6 of the FOOD returns residualized from the predictive model given in column (2) against our PDSIWA36m measure. That is, we are plotting the FOOD returns in excess of the expected returns as captured by the traditional market predictor and industry predictor variables with our drought measure. We then run a simple univariate regression on these residuals. The coefficient is 1.61 with a t-statistic of 2. The coefficient is not identical to column (3) since there is non-zero covariance between PDSIWA36m and the other variables. But since these covariances are not too large, the coefficients are similar in magnitude. Furthermore, the appealing aspect of this scatterplot analysis is that we can see that our drought effect is coming from both negative values of PDSI as well as positive values of PDSI. That is, since PDSI measures the combined moisture in soil and temperature, we expect that when there is less drought (i.e. more moist conditions), we also get higher returns or more profits for the FOOD industry. This difference in the mean FOOD industry returns across drought conditions is visible in the scatterplot.

One important concern is that the t-statistics of our predictability regressions are inflated due to persistent predictor variables since our PDSIWA36m is highly persistent (close to a random walk). To deal with this concern, we implement the Campbell and Yogo (2006) test.

For this test in our baseline case, we do the following. First, we carry out the following two regressions:

$$\text{FOODRET12m}_t = \alpha + \beta \text{PDSIWA36m}_{t-1} + e_t, \quad (3.1)$$

$$\text{PDSIWA36m}_t = \gamma + \rho \text{PDSIWA36m}_{t-1} + u_t, \quad (3.2)$$

where FOODRET12m_t is the future non-overlapping FOOD return over the next 12 months, PDSIWA36m_{t-1} is the moving average of PDSIWA over the previous 36 months, and PDSIWA36m_t is the one-step ahead value of PDSIWA36m_{t-1} (i.e. the contemporaneous value of PDSIWA36m corresponding to FOODRET12m_t). We obtain the residuals from regressions (3.1) and (3.2), and denote them as e_t and u_t respectively. Then we calculate the correlation between the residuals e_t and u_t . The correlation turns out to be merely -0.001 . As shown in Campbell and Yogo (2006), the bias in t -statistics would be a concern if the residuals e_t and u_t are highly negatively correlated. This is not the case in our sample. Furthermore, as demonstrated in their Table 4 and 5 in Campbell and Yogo (2006), when the correlation is very close to zero as opposed to being close to -1 , the confidence intervals for the standard t -test are almost unaffected. Therefore, based on the (extremely) low correlation we find in our sample, we are on safe ground in proceeding with the standard t -test in our analysis and not adjusting the t -statistics values.

3.1.2 Short and Intermediate Horizon Predictability

Our focus on 12-month horizon returns for FOOD brings up the usual worries of long-horizon excess return predictability (Valkanov (2003)). These worries are alleviated somewhat in our setting since our t -statistic is around 2.5 and the scatterplot analysis points to a pronounced decline in expected returns with drought. Nonetheless, to fully address such concerns, we repeat our analysis (column (3) of Table 3) in Table 4 but now using short (1 month) to intermediate horizon returns (3 and 6 months).

In column (1), we consider monthly returns. Our drought predictor attracts a coefficient of .185 with a t-statistic of 1.65. A one standard deviation decrease in our drought measure predicts a decline in next month return by .23%. The mean monthly return for FOOD is .60% with a standard deviation of 4.8%. The economic effect is comparable to the 12-month returns case in Table 3. It is about 40% of the mean FOOD return but a much smaller fraction of the standard deviation of monthly FOOD returns (about 5%). Among the traditional predictors, net equity issuance is the only one that is significant with a coefficient of -.237 and a t-statistic of 3. When compared to these traditional predictors, our drought variable’s excess-return predictability is more striking at the one month horizon than at the 12 month horizon.

In columns (2) and (3), we consider intermediate horizon returns of 3 months and 6 months. In column (2), the coefficient of interest is .558 with a t-statistic of 1.67. A one standard deviation decrease in PDSIWA36m leads to a decline of .70% in next quarter returns, which is around 40% of the mean FOOD return and 7.5% of the standard deviation of FOOD returns. Among the traditional predictors, only net equity issuance and treasury spread are more significant than our variable.

In column (3), the coefficient of interest is 1.062 with a t-statistic of 2.26. The implied economic effect for drought as a fraction of the mean return of FOOD is similar but as a fraction of the standard deviation of FOOD returns, it is closer to the 12-month case (at around 10%). Overall, we conclude that the economic significance of our drought variable is there at short, intermediate and long horizons.

3.1.3 Different Horizon Drought Measures

In Table 5, we explore the extent to which different horizons of our baseline PDSIWA (from 12-month moving average to 30-month moving average) forecast food portfolio returns over the next 12 months. We always use the specification with the full list of control variables from column (3) of Table 3.

In columns (1) and (2), we use a moving average of 12 months and 18 months. We can think of this short-horizon moving average as capturing shorter episodes of drought. The coefficients are positive as before but are not statistically significant. Take the 0.673 coefficient in column (1). A standard deviation of PDSIWA12m is 1.6, which is as expected larger than the standard deviation of 1.26 for our baseline PDSIWA36m measure. Thus a one standard deviation increase in this short-horizon drought measure translates to around a 1% increase in FOOD returns. This economic magnitude is about 40% of that of our 36-month moving average measure. The economic effect is smaller, as we hypothesized, since short duration droughts should have less of an effect on the FOOD industry, all else equal. Indeed, if we took the view that information about a prolonged 36-month drought is much more salient than a 12-month drought and ought to be more readily priced in by the market, then the difference in the predictability generated by the long versus the short-horizon drought measures are even more pronounced.

It is in column (3), at the 24-month moving average horizon, that we see a statistically significant result. The coefficient of interest is 1.264 with a t-statistic of 2.25. Similarly, in column (4), the coefficient is even larger and significant at the 1% level of significance. The implied economic magnitudes are nonetheless smaller than our 36-month moving average baseline measure. Overall, the predictability of FOOD returns by drought information increases the more prolonged the drought is.

3.1.4 Drought Measures Using Different States

In Table 6, we use 36-month moving averages of alternative PDSI measures as the predictor in our baseline regression specification to forecast 12-month FOOD returns. In column (1), the alternative measure is the PDSI using the 48 contiguous US states weighted by cropland area. The coefficient of interest is 2.5 with a t-statistic of 2.4. In column (2), the measure is the PDSI aggregated across the US but weighted by the food cash receipts produced by that state. The coefficient of interest is 2.5 with a t-statistic of 1.9. In column (3), we use the PDSI measure

produced by NOAA. The coefficient is 1.26 and with a t-statistic of 1.77.

All of the alternative drought measures carry comparable statistically significant forecasting power on food portfolio returns. The implied economic effects are also comparable to our top 10 agricultural producing states measure. It is comforting that we can find predictability results even using a coarse PDSI USA measure since for our international analysis below we only have access to such a coarse measure.

3.1.5 Food Returns Net of the Market

We now use our second approach to calculate FOOD returns in excess of the market. Rather than calculating it as a residual from a predictive market model, we simply subtract from the returns of the FOOD portfolio the returns of a market portfolio that excludes the food industry and re-weighted using the other 16 industries. We present the results of a univariate regression of this FOODXMRET on our PDSIWA36m variable in a scatterplot format in Figure 7 with the fitted line drawn. The coefficient of interest is .862 and statistically significant with a t-statistic of 2.14.

This method is by no means perfect and as such we still want to have our control variables in to adjust for potential flaws in our calculation. In Table 7, we do just this. From column (3), our estimate in front of our coefficient of interest is 1.23 with a t-statistic of 3.01. A one standard deviation increase in PDSIWA36m leads to a 1.55% higher return over the next 12 months for FOODXMRET. The mean of FOODXMRET12m is 1% with a standard deviation of 11.75%. The economic significance is comparable to our first method.

3.2 Drought and Profitability Ratios

We now show that the excess predictability patterns of our drought measures for FOOD industry returns are related to more negative cash flow news associated with drought. In Table 8, we take the specifications from Table 3 and replace the dependent variable of future 12-month

FOOD returns with the future 1-year change in the food industry profitability ratio (CP). The change in the food industry profitability ratio in year t is defined as $CP_t = NI_t/A_t - NI_{t-1}/A_{t-1}$, where NI is the food industry net income and A is the food industry total asset. The food industry net income and total asset are obtained respectively by aggregating the net income and the total asset of individual firms within the food industry. We perform the following regression of forecasting the future 1-year change in CP:

$$CP_{t+1} = \alpha + \beta PDSIWA36m_t + \gamma' X_t + \varepsilon_{t+1}, \quad (3.3)$$

where X denotes the control variables apart from PDSIWA36m. This specification is similar to the one used in Fama and French (2000). The one modification of our control variables is that we include in column (2) and (3) of Table 8 the previous 1-year change in the food industry profitability (i.e. CP_t). Otherwise, the control variables are the same as before, which include all of the controls as specified in column (3) of Table 3.

The coefficient of interest is in column (3) where we find that PDSIWA36m attracts a coefficient of 0.10 with a t-statistic of 2.41. Drought is associated with a decline in the food industry profitability over the next year. The standard deviation of CP is 0.77%. Hence, a one standard deviation move in our drought measure results in a 0.12% fall in CP (the standard deviation of PDSIWA36m in our regression (3.3) is 1.2). This is nearly 16% of the standard deviation of CP, which is a substantial decrease.

In Figure 8, we show the scatterplot of the residual of CP generated from the predictive regression in column (2) and our drought measure. The univariate regression through the scatterplot has a coefficient of 0.08 with a t-statistic of 2.47. In short, we confirm that our interpretation of the excess FOOD return predictability regressions are due to the market underreacting to the implications of drought for FOOD industry cash flow-related news.

3.3 Other Industries

We have focused on the returns of the food industry since it is the most directly linked to crops, agricultural production and drought. Our prior is that drought should not significantly predict returns of other industries. To see if this is the case, we run the same predictive regression for each industry in the Fama-French 17-industry categories. Table 9 reports the coefficient estimates and t -statistics of PDSIWA36m for the Fama-French 17 industries and the ranking is based on the magnitude of the t -statistics. As we can see, the Food industry is ranked 1st among all 17 industries for return horizons over future 1 to 12 months. For convenience, we report the coefficients and t -statistics for FOOD, which are the same as those presented earlier. Notice for the 1-month horizon returns, no other industry is significant besides FOOD. The same is true for the 3-month horizon returns and the 6-month horizon returns. At 12 months, Steel is significant besides FOOD but attracts a negative sign. In short, drought only significantly predicts FOOD, consistent with our priors.

Having said this, we are working with very aggregate portfolios. It is possible that perhaps when we consider disaggregated industry portfolios, such as the Fama-French 48 industries categorization, we might see different results. Drought might predict some sub-industries with a positive sign (i.e. they are hurt by drought) and others with a negative sign (i.e. they benefit from drought).

4 International Markets Results

4.1 Food Stock Return Predictability and PDSI

Finally, we examine whether droughts forecast food stock returns in international markets. We consider an international sample of 30 countries, among which 15 are developed countries and 15 are developing countries. In Table 10, we consider how PDSI averaged over 36 months

predict future food industry returns. To increase the power of our test, we exclude countries with less than 10 stocks in the food industry portfolio at any point in time, pool all countries together, and run a panel regression by including a country fixed effect. Controlling for country fixed effect helps isolate the within-country time series return predictability of lagged PDSI from the cross-country effect. Following Petersen (2009), we cluster the standard errors at both the country and month dimensions. The returns are non-overlapping throughout. Similar to Table 3, we present in column (1) the market-wide control variables, including lagged market return, lagged inflation rate, lagged dividend-yield and the lagged market volatility. In column (2), we add the lagged 12-month returns and price-to-book ratio of food industry. In column (3), we then add our PDSI36m, which attracts a coefficient of 3.61 with a t-statistic of 2.18. The mean return of this portfolio is 12.86%. Hence the decrease in returns associated a one standard deviation increase in drought is roughly 45% of the mean. The economic magnitude from our international sample is larger than that of our US results.

In Figure 9, we re-examine the regression results in Table 10 by plotting the residual of FOOD returns from the predictive model in column (2) of Table 10 against our international drought measure PDSI36. The scatterplot depicts an upward sloping or positive relationship between PDSI36m on the x-axis and the FOODRET12m residual on the y-axis. The coefficient from a fitted line through the data is 2.38 with a t-statistic of 2.23.

In Table 11, we examine the excess return predictability at shorter horizons from 1 month to 6 months. In column (1), we consider the 1-month return results. Our market predictor variables MRET12 and MVOL12 are economically and statistically significant. Our coefficient of interest is 0.183 with a t-statistic of 1.86. A one standard deviation increase in PDSI36m (1.49) leads to a higher expected return of .27% next month. The mean 1-month return is 1.04%. This is nearly 26% of the mean. Consistent with the US results, the power of drought to predict FOOD returns is similar as we go further out in horizon up to 6 months.

In Table 12, we use a FOOD industry portfolio return that is net of the market portfolio

of that country. The market portfolio for each country is calculated, as in the case of the US, by excluding food industry stocks. In column (1), we show the monthly return results. The coefficient is 0.153 with a t-statistic of 1.9. All the specifications as we go further out in horizon are economically significant. The only column that is not statistically significant is the 6-month horizon results. The coefficient is sizeable but only attracts a t-statistic of 1.49.

4.2 Profitability Ratios and PDSI

Next we examine whether prolonged drought affects future food industry profitability in international countries. We use the food industry net income (scaled by total assets) as the profitability measure, the same as we do for our US sample. The dependent variable is the future 1-year change in the food industry profitability ratio and the key explanatory variable is the 36-month moving average of country-level PDSI values (PDSI36m). The regression is run by pooling all countries together and controlling for a country fixed effect. Standard errors are double clustered at both the country and month dimensions. The result is reported in Table 13. Consistent with our US result, drought forecasts decreasing food industry profitability over the next year. The coefficient on PDSI36m is 0.180, with a t-stat of 1.75. In sum, our global markets result provides additional evidence that climate risks, such as prolonged droughts, could negatively impact the profitability of food and agricultural sector and stock markets seem to underreact to such prominent risks.

4.3 Cross-Country Portfolio Strategy Based on PDSI

Our time series return predictability test shows that markets underreact to the impact of prolonged drought on the food industry. In this section, we further illustrate our point by utilizing the cross-country PDSI information. Specifically, we construct a trading strategy that is long the food portfolio in countries with high PDSI and short the food portfolio in countries

with low PDSI in any given month.¹³ We expect this strategy to generate abnormal returns if markets indeed underreact to drought contained in the PDSI.

Our trading strategy is constructed as follows. To make the level of PDSI36 comparable across countries, we first standardize the PDSI36 by subtracting its mean and dividing by its standard deviation. We use the past 70 years of PDSI data to calculate a rolling mean and standard deviation of PDSI36. This standardization uses only lagged drought information since we have long time series of drought for all countries. Every month, we sort the food-industry portfolios across all countries into quintiles based on the standardized PDSI36 (denoted as PDSI36*) at the previous month. We then hold each portfolio for K months (where K can range anywhere from 1 month to 12 months) and returns are equally-weighted within each quintile portfolio. We follow Jegadeesh and Titman (1993) to construct the overlapping portfolios. For each quintile portfolio at month t , we have K portfolios formed from month $t - 1$ to $t - K$. Returns on the K portfolios are then equally-weighted to get the average return for each quintile portfolio at month t . The quintile portfolios are rebalanced monthly as we replace $1/K$ fraction of the portfolio that have reached the end of its holding horizons. In addition to the mean portfolio returns, we also report portfolio alphas adjusted using global factor models.¹⁴ Our sample starts from January 1985 when we have at least 10 countries to do the sorting exercise. The result is reported in Table 14.

In Panel A, we report the monthly mean excess returns and factor-adjusted alphas for quintile portfolios with a holding horizon of $K = 12$ months. In the first column, we report the mean standardized PDSI36 for each quintile portfolio. By construction, mean PDSI36* increases monotonically from low to high PDSI countries. Interestingly, we see from column (2) that portfolio returns also increase from low to high PDSI36* countries. The mean excess return for countries in the bottom quintile of PDSI36* is 0.38% per month, and for countries in

¹³US food portfolio is included in our cross-country sample in this test. The results are similar if we exclude the US food portfolio from our sample.

¹⁴The global market, size, book-to-market and momentum factors are the weighted average of the respective country-specific factors, where the weight is the lagged total market capitalization in that country.

the top quintile, the number is 1.15%. The return spread for the long/short strategy is 0.77% per month and significant at 1% level ($t=2.74$). In the last column, we also report the portfolio alphas adjusted using a global Carhart (1997) four factor model. Our results are not affected as the long/short strategy generates a monthly alpha of 0.83% ($t=2.87$). In untabulated tables, we show that a value-weighted long/short portfolio using lagged total market capitalization of the food sector in that country as weight generate a monthly excess return of 0.72% ($t=1.95$) and a four-factor alpha of 0.68% ($t=1.82$).¹⁵

In Panel B, we report the return spread as well as factor-adjusted alphas on this long/short portfolio with holding horizons varying from $K = 1$ month to $K = 12$ months. The mean excess returns are positive and significant across all holding horizons. Consistent with our time series return predictability result, the return spread becomes more pronounced when we increase the holding horizon, indicating that it takes a long time for market to fully incorporate the information about drought into stock prices. For example, the mean monthly excess return on this long/short strategy is 0.77%, with an annualized Sharpe ratio of 0.50. The return decreases to 0.74% when we only hold the portfolio for three months, and further decreases to 0.57% when holding horizon is 1 month. The results are similar whether we adjust the return spread using global Sharpe (1964) CAPM, Fama and French (1993) three factor or Carhart (1997) four factor model as our long/short portfolio has little exposure to these common factors.

Overall, the evidence that countries with low value of PDSI have much lower stock returns on its food industry compared to high PDSI countries provides further evidence that financial markets underreact to prolonged droughts and the need for adequate disclosure on firms' exposure to climate risks.

¹⁵Such a value-weighted portfolio is dominated by the food sector from U.S since the total market capitalization of the food industry is much larger in U.S than in other countries.

5 Conclusion

We show that stock markets are inefficient with respect to information about prolonged drought, one of the most important climate risks that are brought on or exacerbated by climate change. Using a global dataset of the widely-used Palmer Drought Severity Index (PDSI) from climate studies, we show that prolonged drought spells in a country, as measured by a 3-year moving average of PDSI, forecast poor returns for a portfolio comprised of food stocks in that country.

Our findings have a number of implications for policymakers and practitioners. First, our findings confirm regulatory worries about markets underreacting to climate risks and support the need for disclosure of corporate exposures. The question becomes what the best way is to disclose such risks. Second, our findings show that PDSI might be a very useful metric of drought to form portfolios and manage risks. We leave these topics for future research.

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Table 1: Summary Statistics

This table reports the summary statistics for the variables in our sample. The sample is from January 1927 to December 2014 and comprises monthly observations of all variables except FOODBM which is observed annually. Panel A shows PDSIWA, the weighted average Palmer Drought Severity Index (PDSI) values for the top 10 food-producing states (in terms of cash value) in the US. PDSIWA12m to PDSIWA36m denote, respectively, the moving average of the PDSIWA values over 12 months, 18 months, 24 months, 30 months and 36 months. It also shows the 36-month moving average of 3 alternative drought measures: PDSIASWA is the weighted average (based on cropland areas) of the PDSI values of all 48 contiguous US states (excluding Alaska, Hawaii, and Washington D.C. because of no data), PDSIASCA is the weighted average PDSI of all 48 states with the gross cash income of the farm sector in each state as weight, and PDSIUSA is the PDSI of USA produced directly by the US National Oceanic and Atmospheric Administration. Panel B shows the Fama-French 17-industry food industry portfolio non-overlapping excess returns over various horizons. FOODRET is the monthly excess return (net of the 1-month T-bill rate), FOODRET3m to FOODRET12m denote the excess returns over 3 months, 6 months and 12 months respectively, and FOODXMRET12m is the food portfolio return net of the return of the market excluding food (MXF) portfolio over 12 months. Panel C shows the non-overlapping values for other control variables over 12 months. FOODBM is the log value of the value-weighted average of the book-to-market ratios of the firms in the food industry portfolio. MRET is the CRSP value-weighted market portfolio excess return. INF is the CPI inflation rate. DP is the log value of the dividend-price ratio of the S&P 500 index. MVOL is the market volatility (volatility of the S&P 500 index). NTIS is the net equity expansion of the NYSE stocks. DSPR is the default yield spread, the difference between BAA and AAA-rated corporate bond yields. TSPR is the term spread, the difference between the long term yield on government bonds and the Treasury-bill. Panel D gives the correlations among the variables of interest in Panel (A) to (C).

Panel A: Palmer Drought Severity Index (PDSI) Values					
	Mean	S.D.	Median	Min	Max
PDSIWA12m	0.17	1.60	0.54	-4.25	4.10
PDSIWA18m	0.16	1.55	0.51	-3.79	3.64
PDSIWA24m	0.17	1.41	0.42	-3.40	2.99
PDSIWA30m	0.16	1.36	0.29	-3.24	2.83
PDSIWA36m	0.17	1.26	0.29	-3.12	2.53
PDSIASWA36m	0.15	1.06	0.22	-2.35	2.07
PDSIASCAWA36m	0.07	0.89	0.19	-1.95	1.77
PDSIUSA36m	0.17	1.96	0.33	-4.44	4.11

Panel B: Fama-French 17-Industry Food Portfolio Non-overlapping Returns					
	Mean	S.D.	Median	Min	Max
FOODRET (%)	0.60	4.80	0.87	-33.35	28.61
FOODRET3m (%)	1.79	9.37	2.51	-42.59	52.88
FOODRET6m (%)	3.58	12.78	4.51	-42.48	54.73
FOODRET12m (%)	7.16	17.45	8.68	-43.63	39.81
FOODXMRET12m (%)	1.01	11.75	1.37	-37.19	30.87

Panel C: Other Control Variables, Non-overlapping					
	Mean	S.D.	Median	Min	Max
FOODBM12	-0.67	0.46	-0.64	-1.77	0.26
MRET12 (%)	6.02	20.07	9.87	-59.11	45.04
INF12 (%)	2.94	3.96	2.77	-10.93	16.44
DP12	-3.36	0.47	-3.34	-4.48	-2.29
MVOL12 (%)	13.91	8.78	10.94	5.54	50.43
NTIS12 (%)	1.85	2.63	1.76	-4.19	16.35
DSPR12 (%)	1.20	0.79	0.96	0.34	5.10
TSPR12 (%)	1.61	1.42	1.64	-3.50	4.53

Summary Statistics, Continued

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) PDSIWA36m	1													
(2) PDSIASWA36m	0.97	1												
(3) PDSIASCAWA36m	0.94	0.98	1											
(4) PDSIUSA36m	0.88	0.94	0.96	1										
(5) FOODRET12m	0.00	0.01	0.02	0.03	1									
(6) FOODXMRET12m	0.06	0.00	-0.02	-0.04	0.08	1								
(7) FOODBM12	-0.29	-0.30	-0.22	-0.15	0.18	-0.03	1							
(8) MRET12	-0.04	0.00	0.02	0.05	0.82	-0.49	0.18	1						
(9) INF12	0.25	0.27	0.32	0.31	-0.03	-0.12	0.04	0.04	1					
(10) DP12	-0.21	-0.22	-0.15	-0.06	-0.22	0.10	0.81	-0.25	0.02	1				
(11) MVOL12	-0.06	-0.08	-0.12	-0.14	-0.44	0.30	-0.04	-0.55	-0.27	0.24	1			
(12) NTIS12	0.05	0.11	0.12	0.14	-0.20	-0.18	0.03	-0.08	-0.04	0.18	0.05	1		
(13) DSPR12	-0.21	-0.27	-0.26	-0.25	-0.28	0.32	0.25	-0.42	-0.36	0.40	0.73	-0.18	1	
(14) TSPR12	0.05	-0.02	-0.06	-0.06	0.16	0.13	-0.18	0.07	-0.29	-0.14	0.12	-0.14	0.25	1

Table 2: Summary Statistics of the International Sample

This table reports summary statistics of the sample of 30 international countries, including 15 developed countries and 15 developing countries. We report the average number of stocks in the food industry, the median firm market capitalization in US dollars, the mean and standard deviation of the PDSI value and the starting date for each country. Countries with missing variables and less than 10 stocks in the food industry in the whole sample are excluded. The overall sample runs from 1975 to 2013. Stock return data and accounting information for international countries are taken from Datastream and Worldscope, respectively.

Panel A						
Country	Average #	Median Firm Size	Palmer Drought	Severity Index	Start	
Developed Countries	of Stocks	(Million USD)	Mean	Std.	date	
Australia	25	37.65	-0.98	2.16	197501	
Belgium	12	49.06	0.16	2.27	198601	
Canada	16	266.58	-0.40	1.75	197501	
Switzerland	12	163.44	-0.64	2.25	197501	
Germany	15	125.31	-0.66	1.84	198410	
Denmark	9	94.01	0.58	2.41	198804	
Finland	7	154.74	0.87	2.07	199008	
France	26	71.13	-0.58	2.15	197501	
United Kingdom	56	23.70	-0.05	2.27	197501	
Greece	24	33.32	-0.53	2.45	198801	
Israel	23	22.93	0.00	1.78	198601	
Japan	90	158.62	-0.35	2.40	197501	
Netherlands	12	261.64	0.26	2.40	197501	
New Zealand	10	29.25	-0.94	2.03	198801	
Portugal	9	10.32	-0.60	2.45	198801	
Developing Countries						
Brazil	14	160.94	-1.05	1.78	199001	
Chile	20	75.68	-0.46	2.06	198907	
China	54	306.79	-3.08	2.18	199311	
Indonesia	22	56.50	-0.41	1.35	199006	
India	108	2.86	0.94	2.88	199001	
South Korea	39	58.96	-0.24	2.24	198407	
Mexico	9	128.17	0.21	1.85	199107	
Malaysia	50	49.64	1.17	2.55	198601	
Peru	19	19.67	-1.34	2.18	199112	
Philippines	11	39.99	0.29	2.84	199308	
Poland	22	35.22	-0.58	1.68	199410	
Russian Federation	10	101.14	1.27	1.84	200601	
Thailand	32	31.10	-1.23	2.10	198701	
Turkey	17	24.74	2.21	3.04	199011	
South Africa	15	162.98	-0.34	3.05	198703	

Summary Statistics of the International Sample, Continued

This table continues with the summary statistics for the variables in our international sample with all countries pooled together. Panel A shows the summary statistics of our main drought measure and other control variables. PDSI36 is the 36-month moving average of the PDSI for international countries. MRET12, INF12, FOODPB12, DP12 and MVOL12 denote respectively the market excess return, the inflation rate, the price-to-book ratio of food portfolio, the dividend-to-price ratio and market volatility over 12 months. Panel B shows the summary statistics of non-overlapping returns of the food portfolio over different horizons. FOODRET to FOODRET12m denote, respectively, the non-overlapping return over 1 month, 3 months, 6 months and 12 months. FOODXMRET12m is the food portfolio return net of the return of the market excluding food portfolio over 12 months.

Panel B: Drought measure and other controls					
	Mean	S.D.	Median	Min	Max
PDSI36	-0.33	1.49	-0.36	-4.58	5.95
MRET12 (%)	10.25	40.78	11.64	-138.26	435.48
INF12 (%)	2.63	21.09	0.42	-0.44	353.73
FOODPB12	2.58	2.53	2.03	-4.44	30.34
DP12 (%)	3.12	3.96	2.37	0.00	33.61
MVOL12 (%)	23.12	13.74	19.74	6.47	82.27
Panel C: Food Portfolio Non-overlapping Returns					
	Mean	S.D.	Median	Min	Max
FOODRET (%)	1.04	8.74	0.88	-105.17	143.33
FOODRET3m (%)	3.22	16.93	2.8	-87.83	237.11
FOODRET6m (%)	6.42	26.16	5.86	-108.33	420.44
FOODRET12m (%)	12.86	41.30	11.91	-132.06	528.09
FOODXMRET12m (%)	2.93	24.04	2.02	-65.53	99.91

Table 3: Predicting 12-month Non-overlapping Food Portfolio Return with 36-month Moving Average of PDSIWA

This table presents the results from forecasting the future non-overlapping food industry portfolio excess returns (FOODRET) at the 12-month horizon, using the 36-month moving average of the weighted PDSI values (PDSIWA). The dependent variable (forecast) is the non-overlapping food portfolio excess return (FOODRET) over the next 12 months. The key explanatory (forecasting) variable, PDSIWA36m, is the moving average of the weighted PDSI values (PDSIWA) over the previous 36 months. The weighted average is over the top 10 food-producing states using cropland area as weight. Other control variables, FOODRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the FOODRET, the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous 12 months. CONST is the constant term. t -statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The R^2 for each regression is also reported. N is the number of observation points in each regression. The sample period is January 1927 to December 2014. Estimations start in December 1929 as the first 36 months are used to obtain the first value of PDSIWA36m.

	Dependent Variable: Future 12-month FOODRET, Non-overlapping		
	(1)	(2)	(3)
PDSIWA36m			2.005** (2.532)
FOODRET12m		0.012 (0.118)	-0.022 (-0.186)
FOODBM12		14.709 (0.970)	16.899 (1.016)
MRET12	-0.080 (-1.098)	-0.224 (-1.125)	-0.206 (-1.105)
INF12	0.189 (0.738)	0.199 (0.987)	0.031 (0.125)
DP12	7.782*** (6.537)	-4.707 (-0.384)	-5.511 (-0.411)
MVOL12	-0.463* (-1.805)	-0.343 (-1.235)	-0.362 (-1.373)
NTIS12	-2.376*** (-6.921)	-2.204*** (-6.707)	-2.263*** (-6.990)
DSPR12	1.573 (0.686)	-0.193 (-0.061)	0.222 (0.083)
TSPR12	2.300*** (5.937)	2.926*** (4.267)	2.761*** (3.631)
CONST	37.938*** (5.768)	5.600 (0.178)	4.750 (0.137)
R^2	0.22	0.24	0.26
N	85	85	85

Table 4: Predicting Non-overlapping Food Portfolio Returns over Different Horizons with 36-month Moving Average of PDSIWA

This table presents the results from forecasting the future non-overlapping food industry portfolio excess returns (FOODRET) over different horizons, using the 36-month moving average of the weighted PDSI values (PDSIWA). The dependent variables (forecasts) are the non-overlapping food portfolio excess returns (FOODRET) over the next 1 month, 3 months and 6 months in columns 1m, 3m and 6m respectively. The key explanatory (forecasting) variable, PDSIWA36m, is the moving average of the weighted PDSI values (PDSIWA) over the previous 36 months. The weighted average is over the top 10 food-producing states using cropland area as weight. Other control variables, FOODRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the FOODRET, the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous 12 months. CONST is the constant term. t -statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The R^2 for each regression is also reported. N is the number of observation points in each regression. The sample period is January 1927 to December 2014.

	Dependent Variables: Future FOODRET over 1m, 3m and 6m, Non-overlapping		
	1m	3m	6m
PDSIWA36m	0.185* (1.648)	0.558* (1.671)	1.062** (2.260)
FOODRET12m	-0.001 (-0.038)	-0.027 (-0.491)	-0.011 (-0.125)
FOODBM12	0.488 (0.716)	1.929 (0.676)	6.604 (1.171)
MRET12	0.004 (0.235)	-0.011 (-0.212)	-0.111 (-1.371)
INF12	-0.058 (-0.897)	-0.143 (-0.856)	-0.340** (-2.091)
DP12	0.428 (0.702)	1.135 (0.475)	-0.048 (-0.010)
MVOL12	-0.008 (-0.274)	-0.039 (-0.613)	-0.308*** (-2.791)
NTIS12	-0.237*** (-3.003)	-0.877*** (-3.837)	-1.345*** (-3.576)
DSPR12	-0.102 (-0.280)	-0.389 (-0.458)	-0.600 (-0.490)
TSPR12	0.139 (1.618)	0.456** (2.134)	1.382* (1.883)
CONST	2.856 (1.545)	9.138 (1.422)	14.329 (1.133)
R^2	0.02	0.06	0.14
N	1020	340	170

Table 5: Predicting 12-month Non-overlapping Food Portfolio Return with Moving Averages of PDSIWA at Different Frequencies

This table shows the results from forecasting the future non-overlapping food industry portfolio excess returns (FOODRET) at the 12-month horizon, using the moving averages of the weighted PDSI values (PDSIWA) over different frequencies. The dependent variable (forecast) is the non-overlapping food portfolio excess return (FOODRET) over the next 12 months. The key explanatory (forecasting) variables, PDSIWA12m to PDSIWA30m, are the moving averages of the weighted PDSI values (PDSIWA) over the previous 12 months, 18 months, 24 months and 30 months respectively. The weighted average is over the top 10 food-producing states using cropland area as weight. Other control variables, FOODRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the FOODRET, the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous 12 months. CONST is the constant term. t -statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The R^2 and the number of observations (N) in each regression are also reported. The sample period is January 1927 to December 2014. Estimations start in December 1929 to be consistent with our baseline Table 3.

	Dep. Var.: Future 12-month Non-overlapping FOODRET			
	(1)	(2)	(3)	(4)
PDSIWA12m	0.673 (0.454)			
PDSIWA18m		0.752 (0.907)		
PDSIWA24m			1.264** (2.245)	
PDSIWA30m				1.749*** (2.719)
FOODRET12m	0.003 (0.025)	0.002 (0.022)	-0.004 (-0.040)	-0.015 (-0.130)
FOODBM12	15.681 (0.914)	15.719 (0.966)	16.154 (1.012)	16.651 (1.024)
MRET12	-0.224 (-1.190)	-0.224 (-1.178)	-0.220 (-1.172)	-0.209 (-1.131)
INF12	0.110 (0.491)	0.099 (0.485)	0.051 (0.219)	0.018 (0.074)
DP12	-5.246 (-0.391)	-5.161 (-0.402)	-5.273 (-0.412)	-5.370 (-0.411)
MVOL12	-0.357 (-1.452)	-0.357 (-1.375)	-0.362 (-1.351)	-0.355 (-1.326)
NTIS12	-2.233*** (-6.906)	-2.246*** (-6.934)	-2.265*** (-7.040)	-2.280*** (-7.089)
DSPR12	-0.057 (-0.021)	-0.064 (-0.022)	0.019 (0.007)	0.072 (0.026)
TSPR12	2.840*** (4.626)	2.855*** (4.040)	2.811*** (3.700)	2.792*** (3.649)
CONST	4.882 (0.146)	5.224 (0.161)	5.279 (0.161)	5.200 (0.155)
R^2	0.25	0.25	0.25	0.26
N	85	85	85	85

Table 6: Predicting 12-month Non-overlapping Food Portfolio Return with Alternative PDSIWA Measures

This table presents the results from forecasting the future non-overlapping food industry portfolio excess returns (FOODRET) at the 12-month horizon, using the 36-month moving averages of alternative PDSIWA measures. The dependent variable (forecast) is the non-overlapping food portfolio excess return (FOODRET) over the next 12 months. The key explanatory (forecasting) variables in columns (1) to (3) are the 36-month moving averages of, respectively, the weighted average (based on cropland areas) of the PDSI values of all 48 contiguous US states (PDSIASWA), the weighted average PDSI of all 48 states with the gross cash income of the farm sector in each state as weight (PDSIASCABA), and the PDSI of USA produced directly by the US NOAA (PDSIUSA). Other control variables, FOODRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the FOODRET, the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous 12 months. CONST is the constant term. t -statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The R^2 for each regression is also reported. N is the number of observation points in each regression. The sample period is January 1927 to December 2014.

	Dependent Variable: Future 12-month FOODRET, Non-overlapping		
	(1)	(2)	(3)
PDSIASWA36m	2.510** (2.392)		
PDSIASCABA36m		2.516* (1.939)	
PDSIUSA36m			1.263* (1.774)
FOODRET12m	-0.018 (-0.154)	-0.012 (-0.108)	-0.015 (-0.131)
FOODBM12	17.122 (1.022)	16.599 (1.006)	17.578 (1.061)
MRET12	-0.217 (-1.198)	-0.220 (-1.217)	-0.231 (-1.354)
INF12	0.022 (0.086)	0.024 (0.100)	0.015 (0.063)
DP12	-5.616 (-0.416)	-5.572 (-0.420)	-6.923 (-0.525)
MVOL12	-0.379 (-1.404)	-0.352 (-1.246)	-0.337 (-1.196)
NTIS12	-2.309*** (-7.351)	-2.310*** (-7.385)	-2.321*** (-7.498)
DSPR12	0.404 (0.150)	0.062 (0.022)	-0.008 (-0.003)
TSPR12	2.875*** (3.611)	2.923*** (3.747)	2.946*** (3.503)
CONST	4.516 (0.130)	4.445 (0.130)	0.471 (0.014)
R^2	0.26	0.26	0.26
N	85	85	85

Table 7: Predicting 12-month Non-overlapping Food Portfolio net of Market Return with 36-month Moving Average of PDSIWA

This table presents the results from forecasting the future non-overlapping FOODXMRET, the food portfolio return net of the return of the market excluding food (MXF) portfolio, at the 12-month horizon, using the 36-month moving average of the weighted PDSI values (PDSIWA). The dependent variable (forecast) is the non-overlapping FOODXMRET, the food portfolio return net of the return of the market excluding food (MXF) portfolio, over the next 12 months. The key explanatory (forecasting) variable, PDSIWA36m, is the moving average of the weighted PDSI values (PDSIWA) over the previous 36 months. The weighted average is over the top 10 food-producing states using cropland area as weight. Other control variables, FOODXMRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the FOODXMRET, the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous 12 months. CONST is the constant term. t -statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The R^2 for each regression is also reported. N is the number of observation points in each regression. The sample period is January 1927 to December 2014.

	Dependent Variable: Future 12-month FOODXMRET, Non-overlapping		
	(1)	(2)	(3)
PDSIWA36m			1.230*** (3.013)
FOODXMRET12m		0.011 (0.127)	-0.008 (-0.092)
FOODBM12		9.413*** (2.764)	10.737** (2.601)
MRET12	-0.111** (-2.609)	-0.194*** (-3.068)	-0.203*** (-2.983)
INF12	0.097 (0.864)	0.105 (0.732)	0.001 (0.010)
DP12	-5.240 (-1.609)	-13.237*** (-2.669)	-13.710** (-2.387)
MVOL12	-0.334** (-2.166)	-0.257* (-1.688)	-0.269* (-1.761)
NTIS12	0.240 (0.241)	0.354 (0.356)	0.318 (0.319)
DSPR12	4.675*** (2.890)	3.542** (2.437)	3.804*** (2.718)
TSPR12	-0.794 (-1.381)	-0.397 (-0.756)	-0.499 (-1.028)
CONST	-16.251 (-1.139)	-36.973** (-2.007)	-37.445* (-1.821)
R^2	0.07	0.09	0.10
N	85	85	85

Table 8: Predicting 1-year Food Industry Change in Profitability (CP) with 36-month Moving Average of PDSIWA

This table presents the results from forecasting the future 1-year CP, the change in profitability of the food industry over the next year, using the 36-month moving average of the weighted PDSI values (PDSIWA). The dependent variable (forecast) is the CP, the future change in the food industry profitability, over the next year. The key explanatory (forecasting) variable, PDSIWA36m, is the moving average of the weighted PDSI values (PDSIWA) over the previous 3 years (36 months). The weighted average is over the top 10 food-producing states using cropland area as weight. Other control variables, CP1y, FOODRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the change in the food industry profitability, the food industry portfolio return (FOODRET), the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous year (12 months). CONST is the constant term. t -statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The R^2 for each regression is also reported. N is the number of observation points in each regression. The sample period is 1950 to 2014.

	Dependent Variable: Future 1-year Change in Food Industry Profitability		
	(1)	(2)	(3)
PDSIWA36m			0.100** (2.412)
CP1y		-0.101 (-0.942)	-0.125 (-0.969)
FOODRET12m		-0.016*** (-3.668)	-0.017*** (-4.455)
FOODBM12		0.148 (0.714)	0.299 (1.388)
MRET12	-0.003 (-0.633)	0.008* (1.788)	0.008 (1.436)
INF12	-0.078*** (-3.101)	-0.084*** (-3.198)	-0.094*** (-3.480)
DP12	0.157 (1.648)	0.033 (0.142)	-0.068 (-0.282)
MVOL12	0.031*** (3.227)	0.027*** (3.761)	0.026*** (2.804)
NTIS12	0.119** (2.518)	0.089* (1.978)	0.088** (2.018)
DSPR12	0.285 (1.396)	0.319* (1.796)	0.280 (1.453)
TSPR12	-0.002 (-0.105)	0.020 (0.666)	0.009 (0.283)
CONST	0.026 (0.065)	-0.192 (-0.299)	-0.361 (-0.528)
R^2	0.22	0.27	0.29
N	63	63	63

Table 10: International Evidence: Predicting 12-month Non-overlapping Food Portfolio Return

This table presents the results from forecasting the food industry portfolio excess returns over future 12 months, using the moving averages of the PDSI values over the past 36 months (PDSI36m). The regressions are run by pooling all countries together and including a country fixed effect. The dependent variable is the food return over the future 12 month. The returns are non-overlapping. All of the regressions include these other forecasting variables over the past 12 months: lagged food industry return (FOODRET12m), lagged market return (MRET12), lagged inflation rate (INF12), log of food industry price-to-book ratio (FOODPB12), the log of the market dividend price ratio (DP12) and the market volatility (MVOL12). Standard errors are clustered at both the country and month dimensions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The sample period is from January 1975 to December 2015.

Dependent Variable: Future 12-month FOODRET, Non-overlapping			
	(1)	(2)	(3)
PDSI36m			3.6134** (2.18)
FOODRET12m		-0.0989 (-0.97)	-0.0915 (-0.82)
FOODPB12		-12.6849*** (-2.75)	-12.9274*** (-3.07)
MRET12	0.1971 (0.81)	0.2388 (0.77)	0.2433 (0.79)
INF12	2.5230 (0.84)	3.0258 (1.13)	2.4513 (0.97)
DP12	-0.2459*** (-4.62)	-0.3411*** (-9.51)	-0.3513*** (-4.75)
MVOL12	2.5060** (2.05)	2.4319** (2.05)	2.5395** (2.09)
Ave.R-sq	0.178	0.207	0.226
N.of Obs.	585	573	545

Table 11: International Evidence: Predicting Food Industry Portfolio Non-overlapping Returns over Different Horizons

This table presents the results from forecasting the food industry portfolio excess returns (FOODRETs) at various horizons, using the moving averages of the PDSI values over the past 36 months (PDSI36m). The regressions are run by pooling all countries together and including a country fixed effect. The dependent variable 1m is the food return over the next month, and those dependent variables of 3m to 6m are the food returns over the next 3 months and 6 months, respectively. The returns are non-overlapping. All of the regressions include these other forecasting variables over the past 12 months: lagged food industry return (FOODRET12m), lagged market return (MRET12), lagged inflation rate (INF12), log of food industry price-to-book ratio (FOODPB12), the log of the market dividend price ratio (DP12), the market volatility (MVOL12). Standard errors are clustered at both the country and month dimensions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The sample period is from January 1975 to December 2015.

Dependent Variable: Future FOODRET over 1m, 3m and 6m, Non-overlapping			
	(1)	(2)	(3)
PDSI36m	0.1829*	0.6235**	1.3708*
	(1.86)	(2.19)	(2.02)
FOODRET12m	-0.0034	0.0016	0.0357
	(-0.75)	(0.10)	(0.88)
FOODPB12	-1.0013***	-2.9586***	-4.9692***
	(-3.50)	(-3.43)	(-2.77)
MRET12	0.0382*	0.0916	0.1281
	(1.93)	(1.38)	(0.86)
INF12	0.2076	0.8234	0.6561
	(0.86)	(1.07)	(0.52)
DP12	-0.0103	-0.0264	-0.1582***
	(-1.49)	(-1.04)	(-3.34)
MVOL12	0.1680*	0.6297*	1.3149**
	(1.81)	(1.76)	(2.41)
Ave.R-sq	0.058	0.141	0.180
N.of Obs.	6439	2151	1075

Table 12: International Evidence: Predicting Non-overlapping Food Portfolio net of Market Return over Different Horizons

This table presents the results from forecasting the future non-overlapping FOODXMRET, the food portfolio return net of the return of the market excluding food (MXF) portfolio, using the 36-month moving average of the weighted PDSI values (PDSI36m). The dependent variable (forecast) is the non-overlapping FOODXMRET, the food portfolio return net of the return of the market excluding food (MXF) portfolio, over the next 1 months to 12 months. The returns are non-overlapping. All of the regressions include these other forecasting variables over the past 12 months: lagged food industry return net of market return (FOODXMRET12m), lagged market return (MRET12), lagged inflation rate (INF12), log of food industry price-to-book ratio (FOODPB12), the log of the market dividend price ratio (DP12) and the market volatility (MVOL12). Standard errors are clustered at both the country and month dimensions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The sample period is from January 1975 to December 2015.

Dependent Variable: Future FOODXMRET over 1m, 3m, 6m and 12m, Non-overlapping				
	1m	3m	6m	12m
PDSI36m	0.1525*	0.3248	0.6434	1.4493**
	(1.90)	(1.55)	(1.49)	(2.11)
FOODXMRET12m	-0.0247	-0.0200	-0.0414	0.0014
	(-1.51)	(-0.93)	(-0.80)	(0.02)
FOODPB12	-0.5538*	-1.2220*	-2.3489	-4.0805
	(-2.00)	(-1.83)	(-1.64)	(-1.47)
MRET12	-0.0036	0.0037	0.0093	0.0352
	(-0.70)	(0.46)	(0.46)	(1.54)
INF12	0.0199	0.1495	-0.0572	-0.7591
	(0.29)	(0.92)	(-0.16)	(-1.13)
DP12	-0.0141	-0.0139	-0.0113	-0.0409
	(-1.16)	(-0.82)	(-1.00)	(-1.15)
MVOL12	0.0187	0.2167	0.1129	-0.0917
	(0.49)	(1.64)	(0.36)	(-0.18)
Ave.R-sq	0.010	0.021	0.038	0.064
N.of Obs.	6429	2131	1055	525

Table 13: International Evidence: Predicting 1-year Food Industry Change in Profitability (CP) with 36-month Moving Average of PDSI

This table presents the results from forecasting the future 1-year CP, the change in profitability of the food industry over the next year, using the 36-month moving average of the PDSI values (PDSI). The dependent variable (forecast) is the CP, the future change in the food industry profitability, over the next year. The key explanatory (forecasting) variable, PDSI36m, is the moving average of the PDSI values (PDSIWA) over the previous 3 years (36 months). Other control variables, CP1y, FOODRET12m, FOODPB12, MRET12, INF12, DP12 and MVOL12 denote, respectively, the change in the food industry profitability, the food industry portfolio return (FOODRET), the log of the food industry price-to-book ratio (FOODPB), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP) and the market volatility (MVOL). We control for country fixed effect in the regression and standard errors are double clustered along the country and month dimension. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The sample period is 1975 to 2015.

	Dependent Variable: Future 1-year Change in Food Industry Profitability		
	(1)	(2)	(3)
PDSI36m			0.1801* (1.75)
CP1y		-0.4609*** (-12.37)	-0.4564*** (-10.41)
FOODRET12m		0.0007 (0.10)	0.0002 (0.03)
FOODPB12		-0.0406 (-0.25)	-0.1431 (-1.06)
MRET12	-0.0029 (-0.54)	0.0019 (0.27)	0.0021 (0.39)
DP12	-0.0313** (-2.60)	-0.0376 (-1.05)	-0.0448 (-1.13)
INF12	-0.0005** (-2.13)	-0.0003 (-0.44)	-0.0004 (-0.51)
MVOL12	0.0859*** (3.23)	0.0483 (1.51)	0.0431 (1.61)
Ave.R-sq	0.017	0.207	0.206
N.of Obs.	703	689	651

Table 14: Return to Portfolio Strategies Sorted on Standardized PDSI36m

This table presents the returns and alphas (in percentage) to country food portfolios sorted on lagged PDSI36m. PDSI36m is first standardized by subtracting its mean and divide by its standard deviation. We estimate the rolling mean and standard deviation of PDSI36m with past 70 years of data. Each month all country food-industry portfolios are sorted into quintiles based on their standardized PDSI36m (denoted as PDSI36m*) from the previous month end and held for various horizons from 1 month to 12 months. In panel A, we report the mean PDSI36m*, excess returns and Carhart four factor alphas for quintile portfolios with a holding period of 12 months. In panel B, we report the long/short return spread and factor-adjusted alphas from 1 month to 12 months. The alphas are adjusted using global Sharpe (1964) CAPM, Fama and French (1993) three factors and Carhart (1997) four factors model following the methodology of constructing local factors. The sample period is from January 1985 to December 2015.

Panel A: Quintile Portfolios sorted on standardized PDSI36m					
Portfolio	PDSI36m*	Excess Return	t-stat	4-factor alpha	t-stat
Low PDSI	-1.60	0.38	1.31	0.27	1.04
2	-0.78	0.77	2.94	0.64	2.87
3	-0.28	0.46	1.76	0.33	1.46
4	0.25	0.91	3.53	0.81	3.84
High PDSI	1.37	1.15	3.87	1.10	4.28
High - Low	2.97	0.77	2.74	0.83	2.87

Table 14 Continued

Panel B: L/S Portfolios sorted on standardized PDSI36m for various holding horizons					
		12-month Holding Period			
	Excess Return	CAPM alpha	Three-factor alpha	Four-factor alpha	
Mean	0.77	0.76	0.80	0.83	
t-stat	2.74	2.69	2.78	2.87	
Std.Dev	5.34				
Sharpe Ratio	0.50				
No.of obs.	360				
		6-month Holding Period			
	Excess Return	CAPM alpha	Three-factor alpha	Four-factor alpha	
Mean	0.74	0.73	0.75	0.81	
t-stat	2.49	2.45	2.46	2.63	
Std.Dev	5.68				
Sharpe Ratio	0.45				
No.of obs.	360				
		3-month Holding Period			
	Excess Return	CAPM alpha	Three-factor alpha	Four-factor alpha	
Mean	0.72	0.71	0.72	0.80	
t-stat	2.38	2.34	2.35	2.58	
Std.Dev	5.74				
Sharpe Ratio	0.43				
No.of obs.	360				
		1-month Holding Period			
	Excess Return	CAPM alpha	Three-factor alpha	Four-factor alpha	
Mean	0.57	0.56	0.56	0.66	
t-stat	1.84	1.81	1.79	2.09	
Std.Dev	5.86				
Sharpe Ratio	0.34				
No.of obs.	360				

Figure 1: Historical PDSI of the US

This figure illustrates the historical PDSI of the US produced directly by the US NOAA. The PDSI value is shown on the vertical axis. The horizontal axis is time. The PDSI of the US is essentially a land-area weighted average of the PDSI values from all climate divisions in the US.

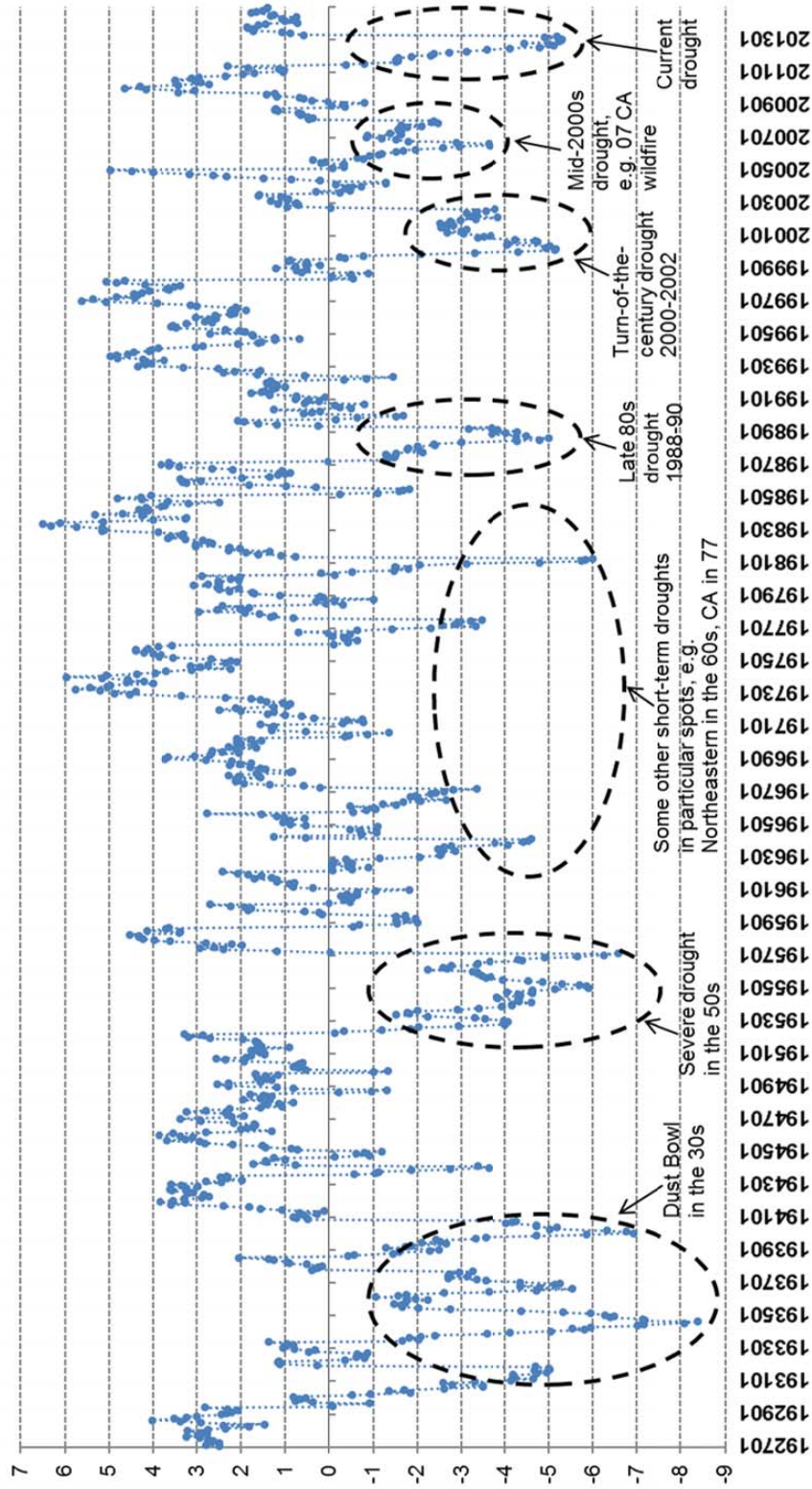


Figure 2: Historical PDSI of California

This figure illustrates the historical PDSI value of California. The PDSI value is shown on the vertical axis. The horizontal axis is time.

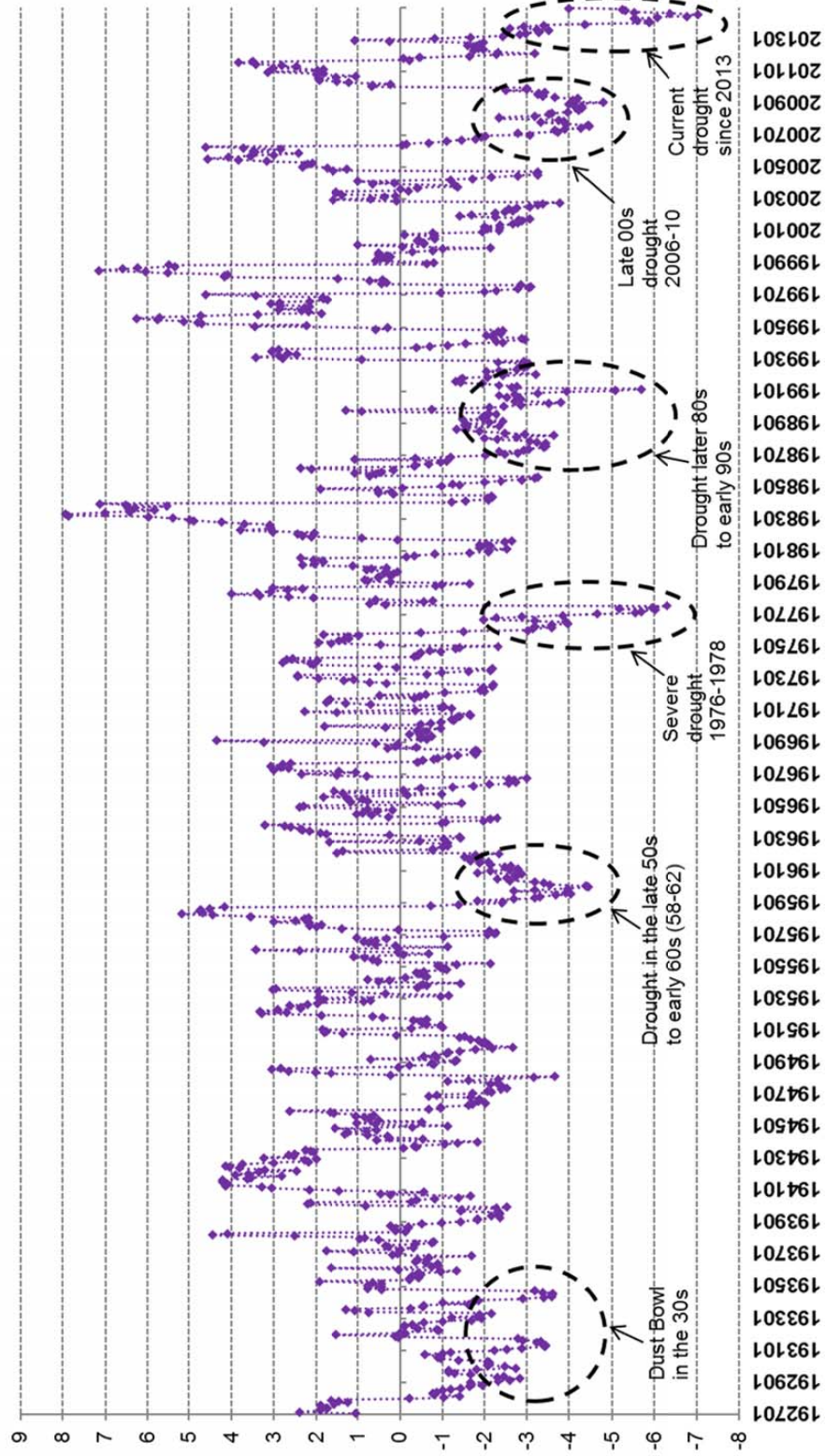


Figure 3: Historical PDSI of Texas

This figure illustrates the historical PDSI value of Texas. The PDSI value is shown on the vertical axis. The horizontal axis is time.

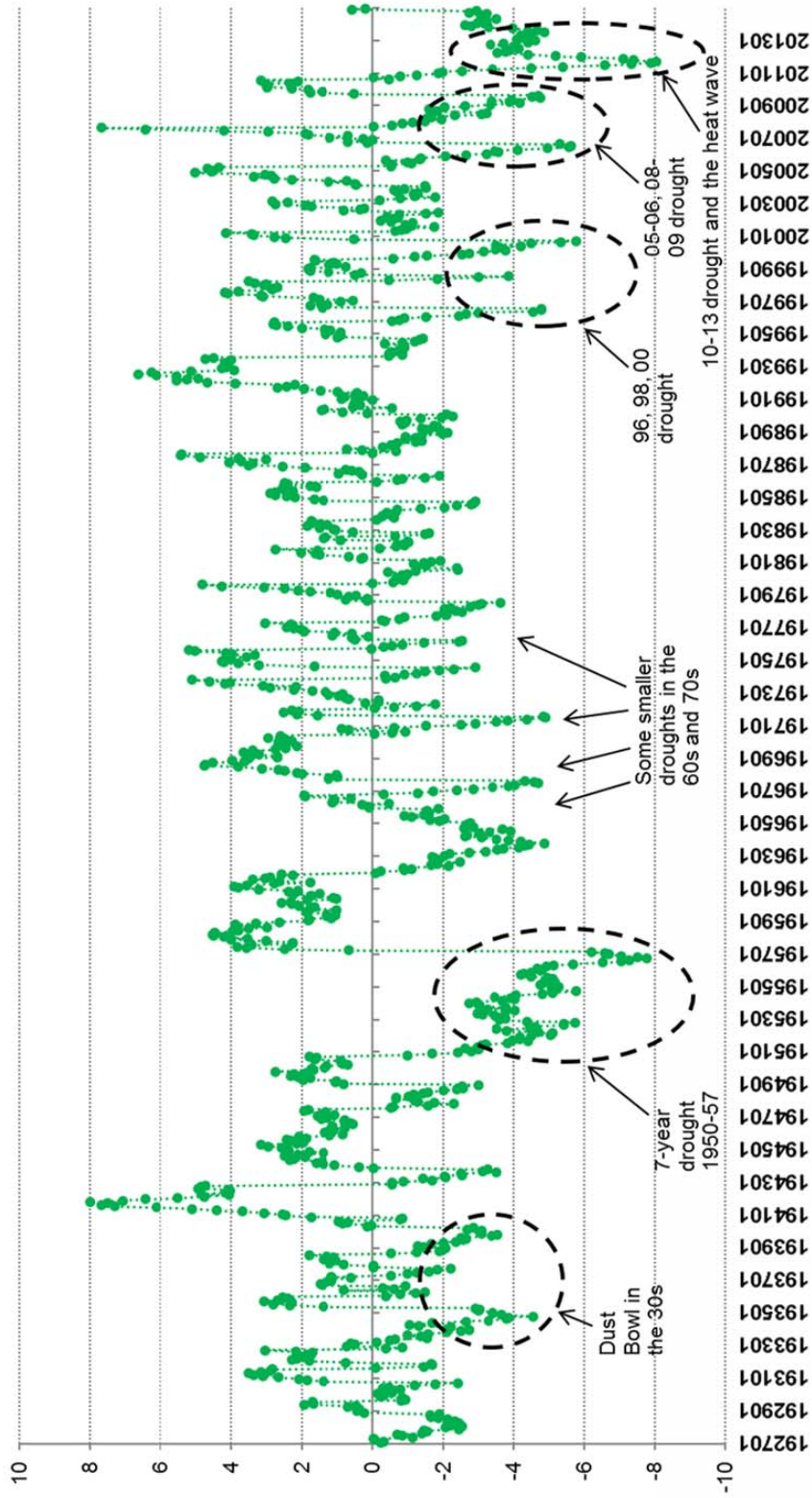


Figure 4: Future Non-overlapping 12-month Return of Food net of Market Portfolio and Past 36-month Moving Average of PDSIWA, Time-series Plot

This figure depicts the time-series plot of the future non-overlapping 12-month return of the food net of market portfolio against our main predictor variable PDSIWA36m, the past 36-month moving average of the weighted average (by cropland area) PDSI value of the top 10 food-producing states in the US. The sample period is January 1927 to December 2014. The plot starts in December 1929 as the first 36 months are used to obtain the first value of PDSIWA36m.

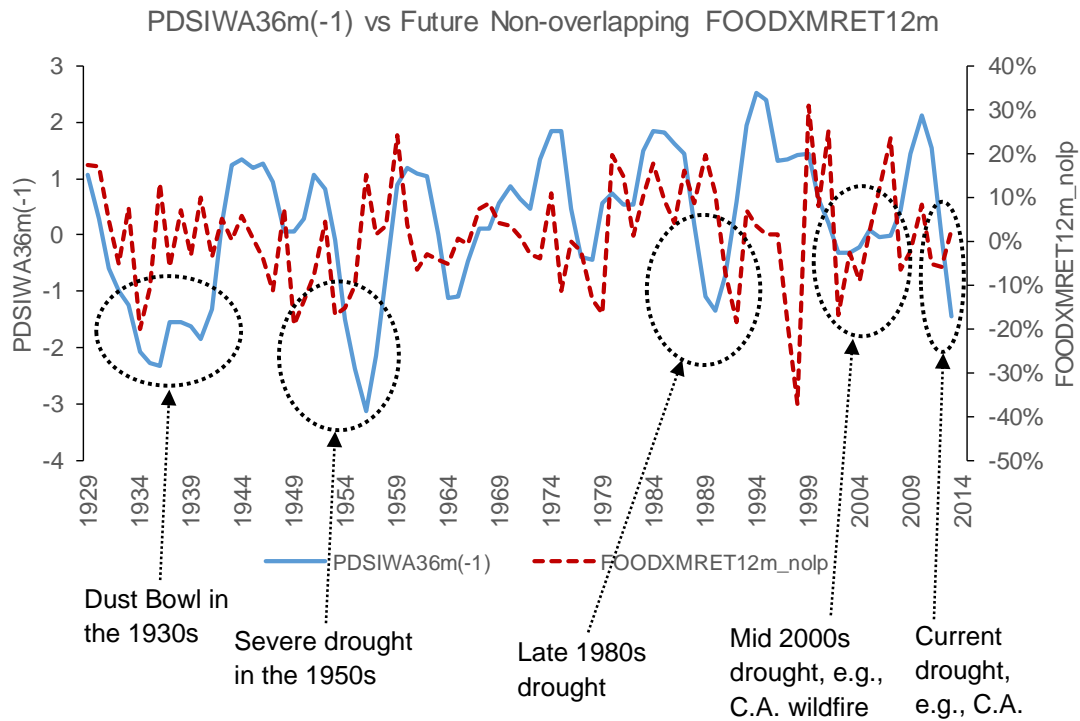


Figure 5: Historical PDSI for Selective Countries

This figure plots the time series of monthly PDSI value for Australia, China, UK, Russia and Canada. The sample period runs from January of 1927 to December of 2014. The PDSI value is shown on the vertical axis. The horizontal axis is time.

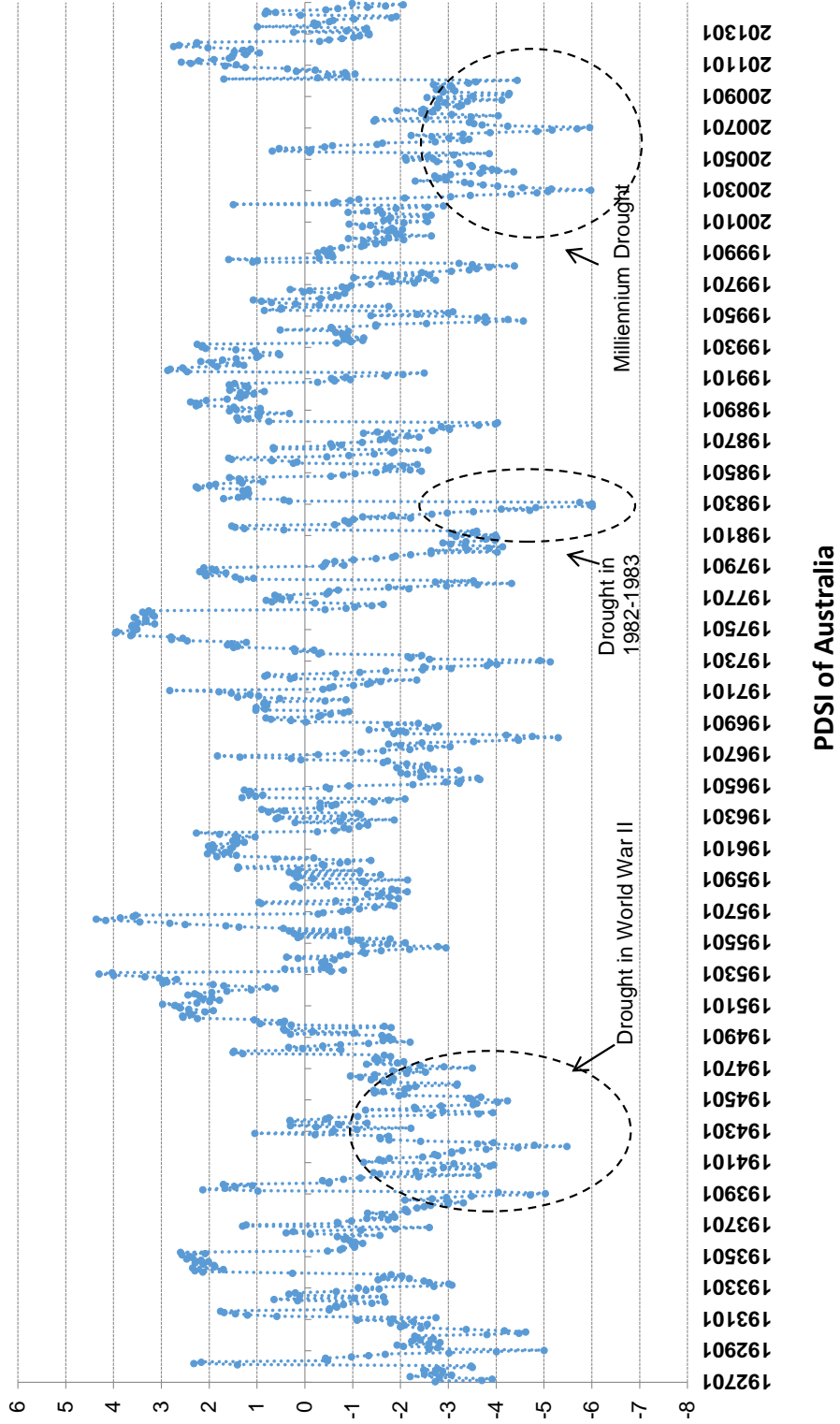


Figure 5 Continued

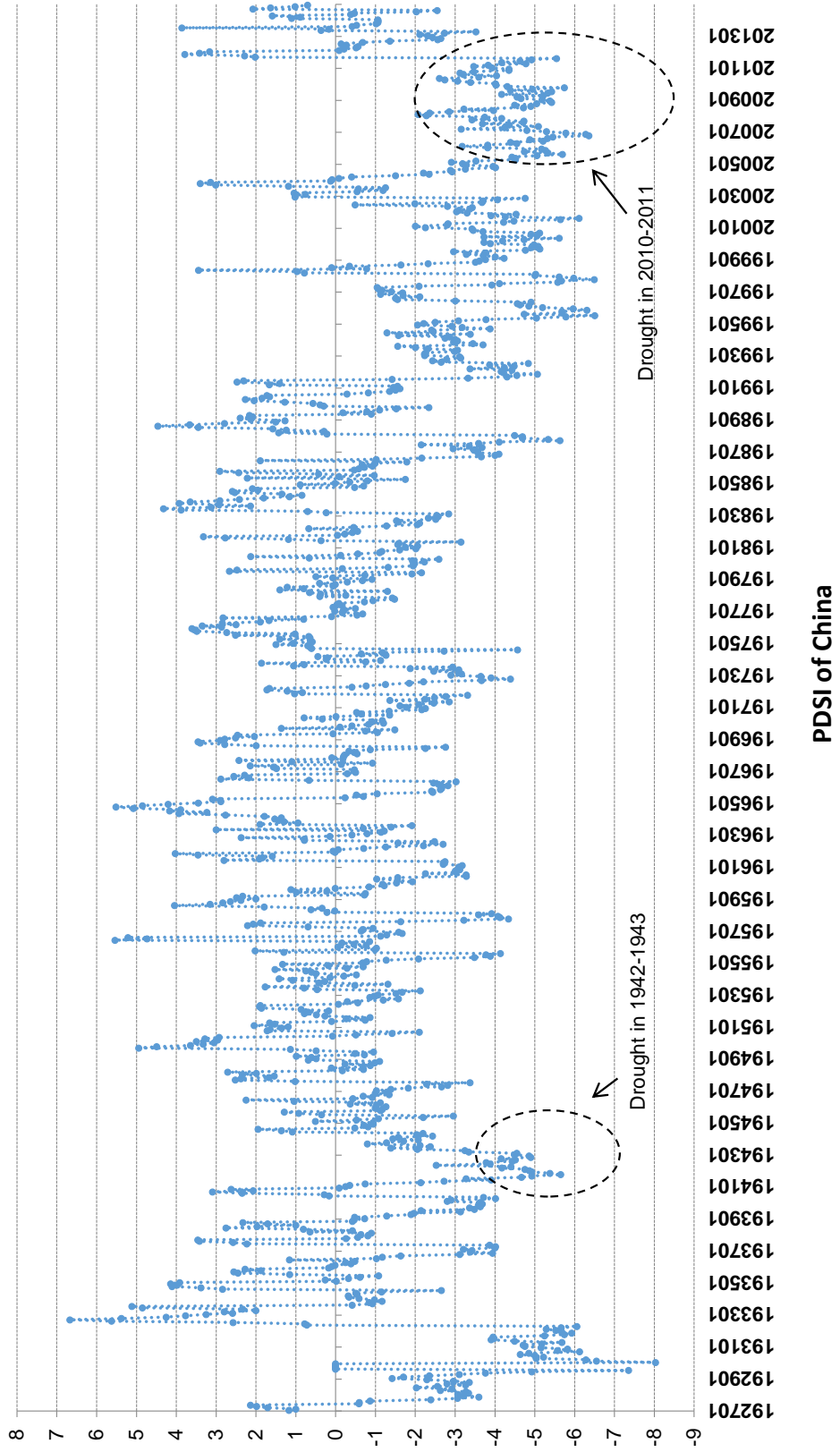


Figure 5 Continued

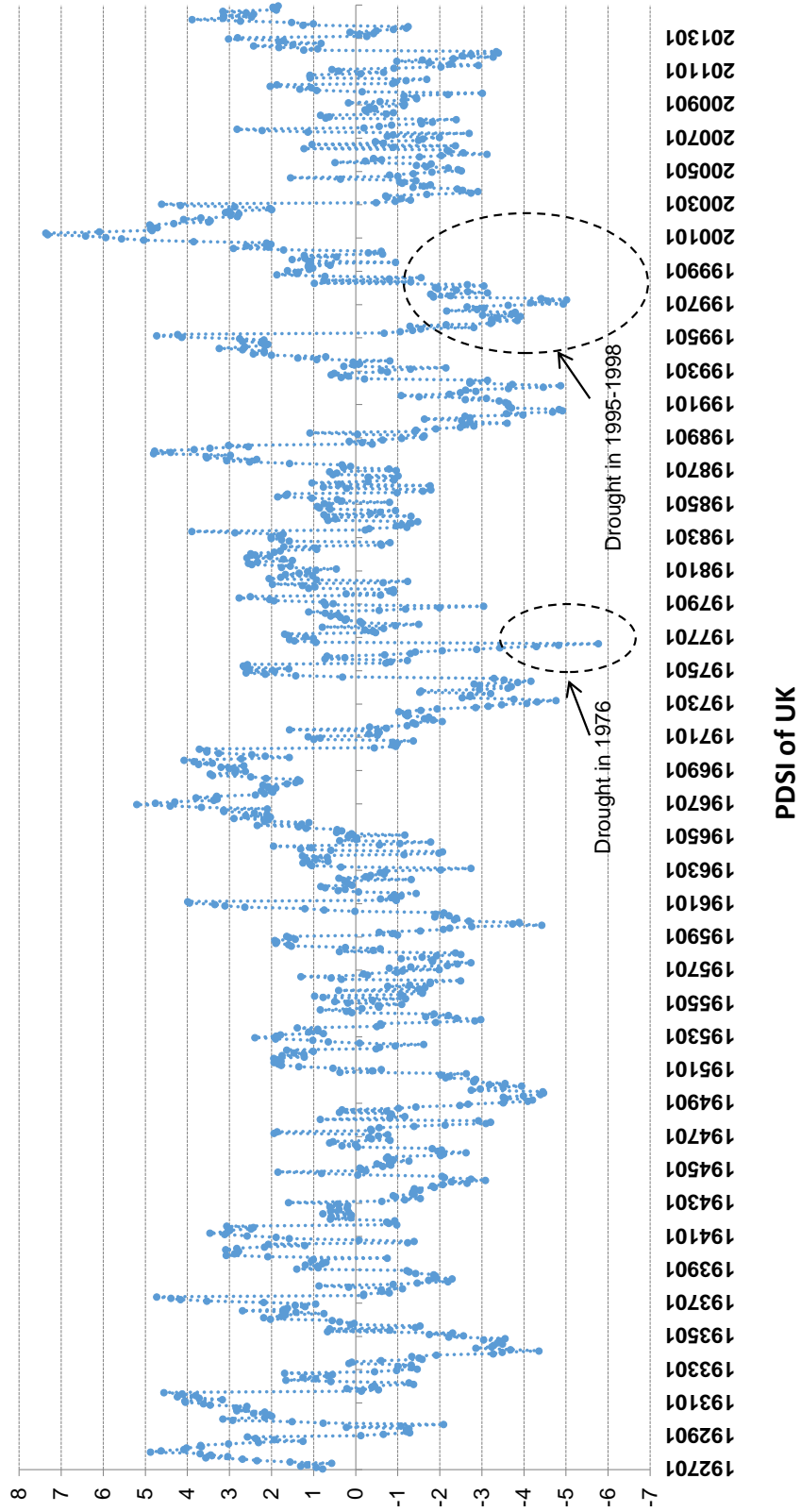


Figure 5 Continued

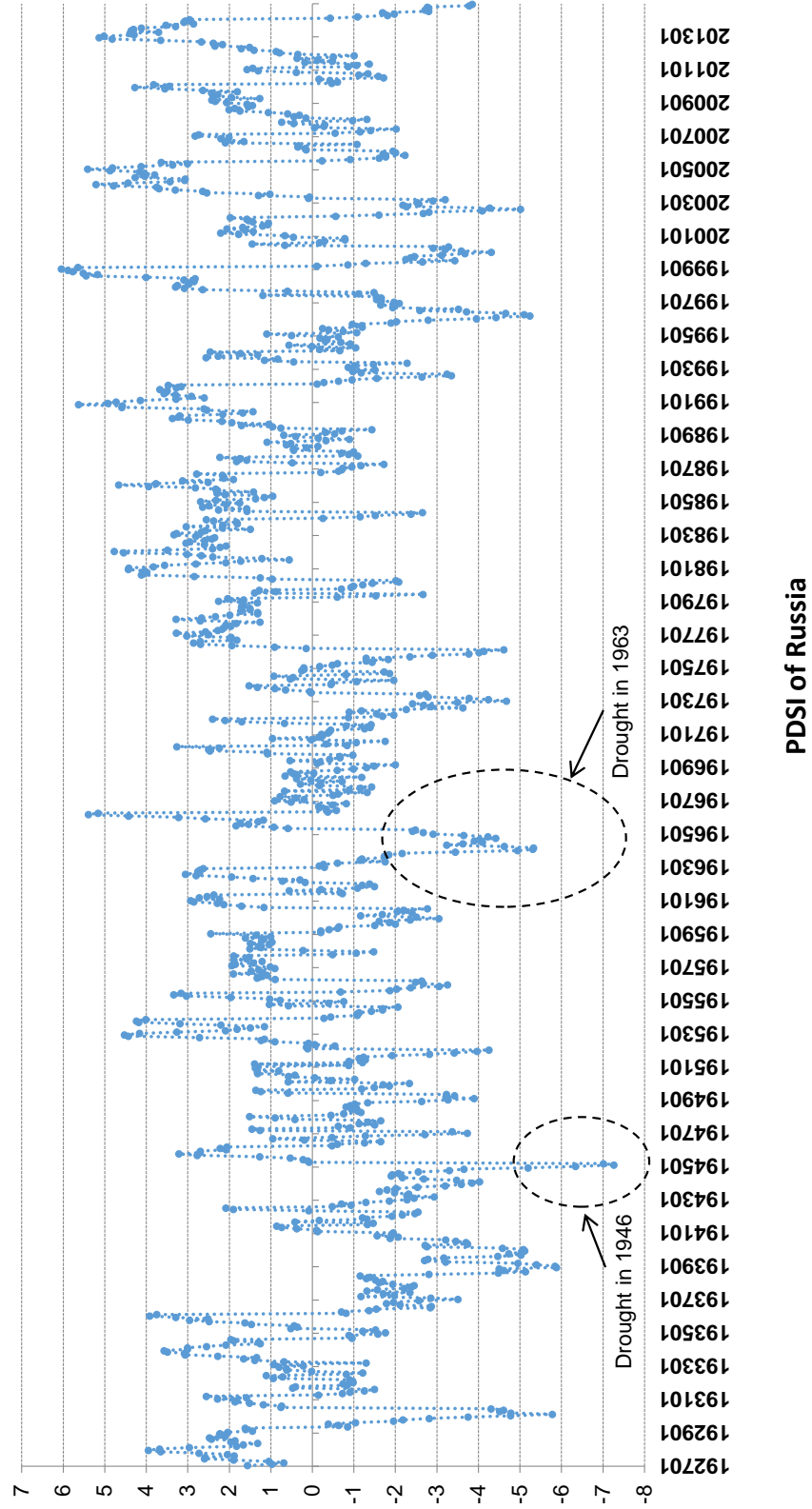


Figure 5 Continued

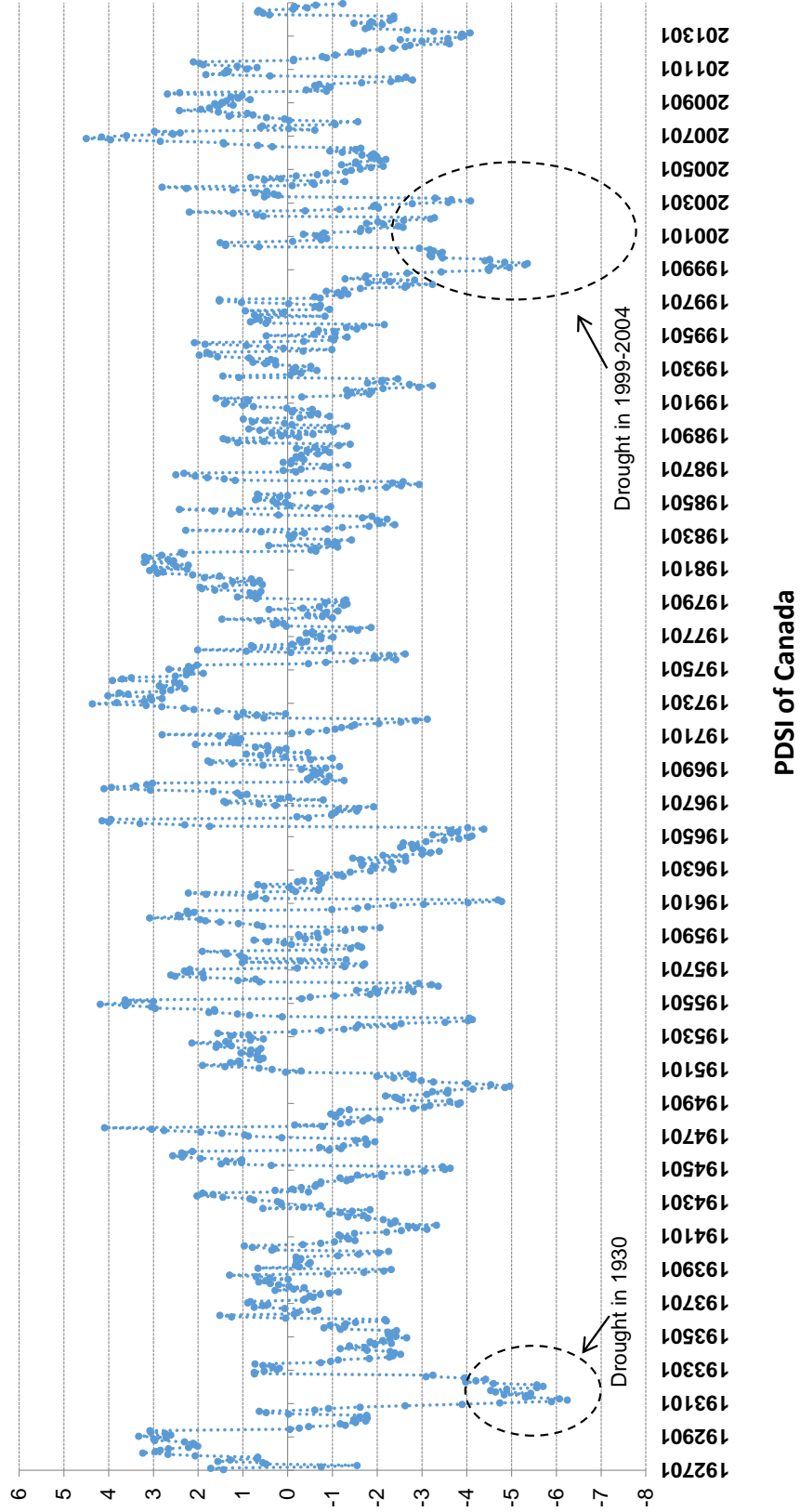


Figure 6: Future Non-overlapping 12-month Food Portfolio Return Residual and Past 36-month Moving Average of PDSIWA, Scatter Plot

This figure depicts the scatter plot of the future non-overlapping 12-month food portfolio return residual against our main predictor variable PDSIWA36m, the past 36-month moving average of the weighted average (by cropland area) PDSI value of the top 10 food-producing states in the US. The sample period is January 1927 to December 2014. The plot starts in December 1929 as the first 36 months are used to obtain the first value of PDSIWA36m.

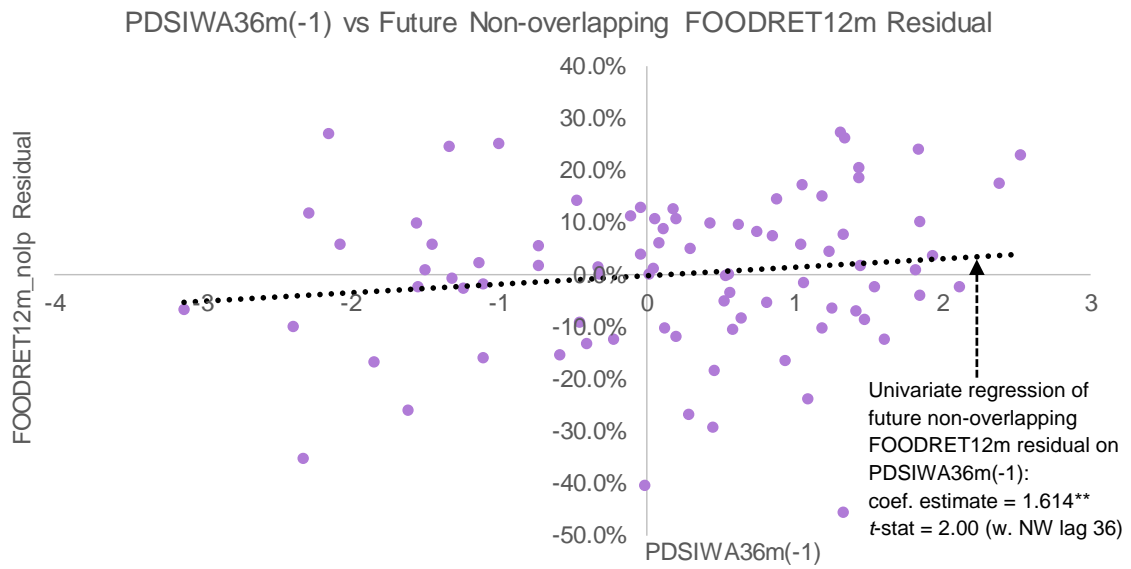


Figure 7: Future Non-overlapping 12-month Return of Food net of Market Portfolio and Past 36-month Moving Average of PDSIWA, Scatter Plot

This figure depicts the scatter plot of the future non-overlapping 12-month return of the food net of market portfolio against our main predictor variable PDSIWA36m, the past 36-month moving average of the weighted average (by cropland area) PDSI value of the top 10 food-producing states in the US. The sample period is January 1927 to December 2014. The plot starts in December 1929 as the first 36 months are used to obtain the first value of PDSIWA36m.

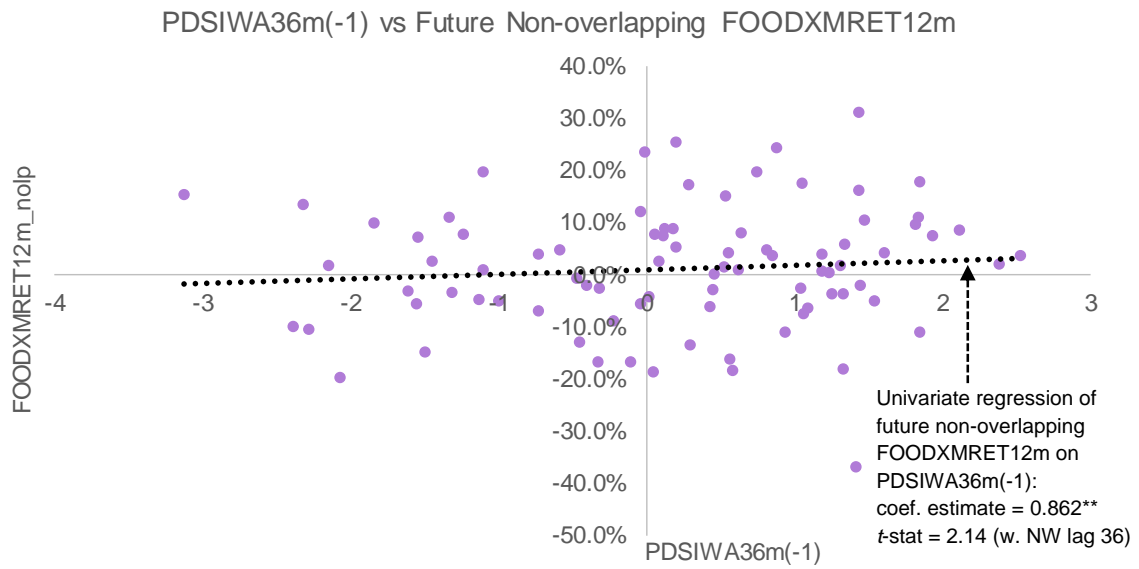


Figure 8: Future 1-year Change in Food Industry Profitability (CP) Residual and Past 36-month Moving Average of PDSIWA, Scatter Plot

This figure depicts the scatter plot of the future 1-year change in the food industry profitability (CP) residual against our main predictor variable PDSIWA36m, the past 36-month (3-year) moving average of the weighted average (by cropland area) PDSI value of the top 10 food-producing states in the US. The sample period is 1950 to 2014.

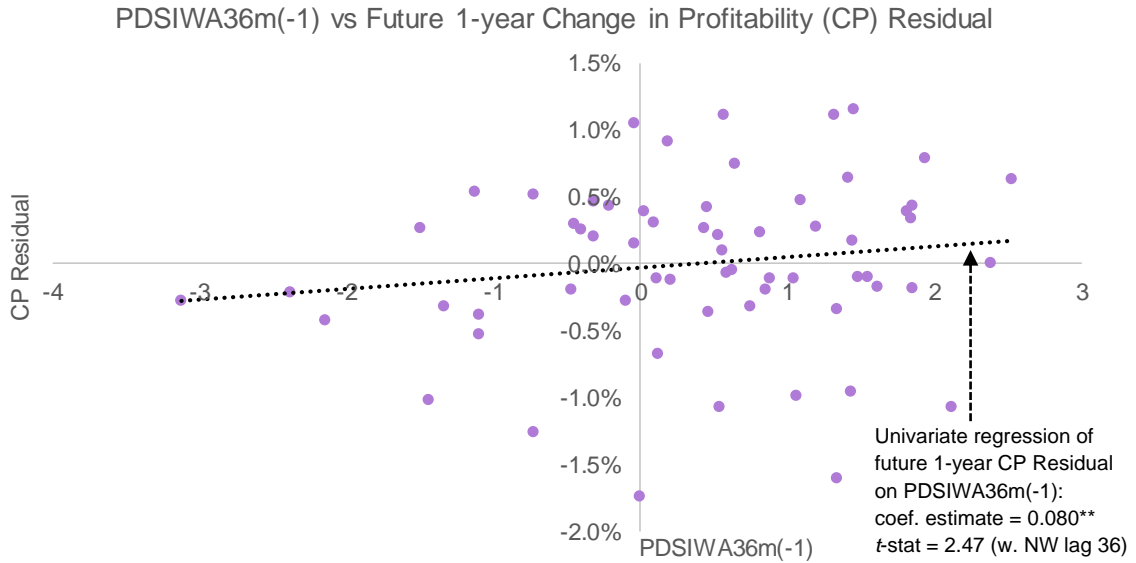


Figure 9: International Evidence: Future Non-overlapping 12-month Food Portfolio Return Residual and Past 36-month Moving Average of PDSI, Scatter Plot

This figure depicts the scatter plot of the future non-overlapping 12-month food portfolio return residual against our main predictor variable PDSI36, the past 36-month moving average of PDSI value. The sample period is from January 1975 to December 2015.

PDSI36m(-1) vs Future Non-overlapping FOODRET12m Residual

