ISSN 1518-3548

BANCO CENTRAL DO BRASIL

Does Extreme Rainfall Lead to Heavy Economic Losses in the Food Industry?

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August 2017

Working Papers

462

ISSN 1518-3548
CGC 00.038.166/0001-05

Working Paper Series	Brasília	no. 462	August	2017	p. 1-25

Working Paper Series

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Non-technical Summary

Managing risks associated with global food production is a permanent challenge for governments. In particular, extreme weather events have threatened production in the food industry in recent years. In response to this issue, the literature has been evaluating the economic impacts of extreme climate changes, but there is still little research addressing the impacts of these changes on companies. To reduce this gap, this article analyzes the impact of extreme rainfall events on the food industry in Brazil, an emerging economy that is a prominent player in this sector.

Economic theory states that the price of an asset reflects the present value of expected future cash flows adjusted by the risk. This statement, together with the market efficiency hypothesis, tell us that stock prices should reflect any information about the future states of nature. Therefore, we can observe if extreme weather events affect companies through their own stock prices.

Specifically, in this paper, we analyze whether extreme rainfall events affect the prices of six stocks of food industry companies listed in the Brazilian stock exchange. The results indicate that these events have a strong impact on the stock returns: On more than half of the days immediately after extreme rain events, which occurred between 2.28.2005 and 12.30.2014, returns were significantly low, causing average daily losses of 1.97%. These results point to the need for more accurate financial management to hedge against weather risk.

Sumário Não Técnico

A gestão dos riscos associados à produção mundial de alimentos se constitui em um desafio permanente para os governos. Em particular, eventos climáticos extremos têm ameaçado a produção da indústria alimentícia nos últimos anos. A literatura acadêmica vem avaliando os impactos econômicos decorrentes de mudanças climáticas extremas, mas poucas pesquisas têm sido realizadas sobre os impactos dessas mudanças nas empresas. Para reduzir essa lacuna, este artigo analisa o impacto de eventos de precipitação extrema na indústria de alimentos do Brasil, o qual é um importante ator nesse setor.

A teoria econômica afirma que o preço de um ativo reflete o valor presente dos seus fluxos de caixa futuros esperados e ajustados pelo risco. Essa afirmação, juntamente com a hipótese de eficiência do mercado, nos diz que qualquer informação sobre os futuros estados da natureza da empresa deve se refletir nos preços de suas ações. Portanto, podemos observar se eventos climáticos extremos afetam as empresas por intermédio dos preços de suas ações.

Especificamente, neste trabalho, analisamos se eventos de precipitação extrema afetam os preços de seis ações de empresas da indústria de alimentos listadas na bolsa de valores brasileira. Os resultados indicam que esses eventos têm um forte impacto nos retornos das ações: em mais da metade dos dias imediatamente após os eventos de chuva extrema, entre 28/2/2005 e 30/12/2014, os retornos foram significativamente baixos, causando perdas diárias médias de 1,97%. Esses resultados apontam para a necessidade de uma gestão financeira mais precisa para proteção das empresas contra o risco climático.

Does Extreme Rainfall Lead to Heavy Economic Losses in the Food Industry?

Edimilson Costa Lucas*

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Abstract

Natural extreme events have been occurring more frequently with growing impacts in well-being, mainly in emerging economies. Therefore, the need for more accurate information for managing such impacts has grown. In response to this issue, financial literature has been focusing on the assessment of economic impacts that arise from extreme weather changes. However, these efforts have imparted little attention to the economic impact analysis at the corporate level. To reduce this gap, this article analyzes the impact of extreme rainfall events on the food industry in an emerging economy that is a prominent player in this sector, Brazil. For this purpose, we use the AR-GARCH-GPD hybrid methodology to identify whether extreme rainfalls affect stock prices of food companies. The results indicate that these events have a strong impact on the stock returns: In more than half of the days immediately after extreme rain events that occurred between 2.28.2005 and 12.30.2014, returns were significantly low, causing average daily losses of 1.97%. These results point to the need for more accurate financial management to hedge against weather risk.

Keywords: Extreme Weather Events, Extreme Value Theory, Firm value, Weather Derivatives, Economic Impacts, Food Industry.
JEL Classification: G12, G31

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1. Introduction

Managing risks associated with global food production is a permanent challenge for governments (Ghosh, 2010). In particular, extreme weather events have threatened the production in the food industry in recent years (World-Bank, 2015b). In response to this issue, the financial literature has documented efforts aimed at evaluating the economic impacts arising from extreme climate changes, but there is still little research addressing the effects of these changes on firms.

The objective of this work is to evaluate the impact of extreme weather changes on companies in the food sector. The specific weather event considered in this study is the extreme rainfall. Taking into consideration that direct or indirect losses caused by extreme rainfalls affect farmers and investors (Cabrera *et al.*, 2013), this study analyzes whether these weather events have an influence on food sector share prices, and if so, what the magnitude of this impact is. In this case, why does this study use financial returns as variables to recognize the impact of extreme rainfall on food companies? The economic theory states that the price of an asset reflects the present value of its expected future earnings adjusted by risk. This statement, together with the market efficiency hypothesis, tell us that any information about the future states of nature should be reflected in the stock prices. Therefore, if extreme rainfall affects firms, this fact will be reflected in their returns.

Concomitantly, emerging countries especially Brazil has a growing need for understanding this issue to improve the assertiveness in their management efforts. Brazil is a major producer and exporter of various agricultural products (CEPEA, 2015), due to its favorable soil and climate conditions and the technological development of its agribusiness. Moreover, as it has continental dimensions, the country is subject to adverse weather (drought, hail and rain, especially) that can directly or indirectly affect its agricultural production (Marengo *et al.*, 2009).

According to CEPEA (2015), the agribusiness sector in Brazil is responsible for a representative proportion of its GDP (approximately 23% in 2015), for underpinning the country's trade balance and for guaranteeing food security, thus avoiding a disorderly increase in the price of food and other agricultural commodities.[1]

[1] Between 2000 and 2014, the Brazilian agribusiness trade balance grew by around 468%. In the accumulated figures for this same period, more than US$ 500 billion net was generated, more than US$ 80 billion of which was in 2014 alone (CEPEA, 2015).

In order to evaluate the impact of extreme weather changes on companies in the food sector in Brazil, this study considers, for the sample initial date of each company, the day its stocks were first publicly traded on the Brazilian stock exchange. The final date is always 12/30/2014. Also, the daily rainfall event refers to the location of the main region in which each company operates (Pérez & Yun, 2013) and was taken from the *INMET's* Meteorological Database for Teaching and Research (*BDMEP*, 2015).[2] This study considers daily rainfall in excess of 50 mm to be extreme, as detailed by Walter (2007).

For modeling the returns on the stocks, this study uses traditional temporal series techniques, in view of the fact that, generally speaking, financial return series tend to deal with temporal dependence and volatility clusters. Therefore, daily returns are adjusted using an AR-GARCH model (McNeil e Frey, 2000; Mendes, 2000). Based on the standardized residuals for this model, the value at risk (VaR) is estimated, using the Extreme Value Theory (Zhao *et al.*, 2010).

Therefore, the VaR is calculated using an AR-GARCH-GPD model.[3] The value at risk measures are estimated for the day after extreme rainfall events, in order to analyze the impact of these occurrences on the stocks being studied. If the negative return on the share (in module) is greater than the estimated VaR, then the impact of the extreme rainfall is considered to be significant.

The results show that extreme rainfall events had a significant impact on the stock returns in more than half the events and caused average daily losses of 1.97% on the day after the extreme rainfall. In terms of market value, this represents a total average loss of around US$ 682.15 million in a single day.

As the analyzed companies have no positions in weather derivatives, this paper points to how important it is for the managers of food production companies to concern themselves with mitigating risks arising from extreme rainfall, since this can improve their productivity by reducing the financial restrictions to agricultural production (Cornaggia, 2013). This study also underlines the relevance of having weather derivatives (hedge instruments) available in the financial market.

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[2] *INMET* – Brazilian Meteorology Institute.

[3] GPD is the acronym for generalized Pareto *d*istribution. Gnedenko (1943) shows that the tails of a great spectrum of probability distributions share common properties: the distributions of the tails converge to the generalized Pareto distribution when the initial quantile of the tail increases.

This article is included in the literature about the evaluation of the economic impacts of extreme weather events. It contributes to the limited bibliography that exists on the relationship between weather variables and company valuation. It also uses the extreme value theory to establish whether the financial losses on stocks are significant when an extreme event occurs.

This work is structured in 5 sections. In addition to this introduction, the theoretical reference is presented in Section 2, in which this study reviews the literature related to the topic of this study and present the Extreme Value Theory that supports this study. In Section 3, this paper presents the data and details the methodology. Section 4 presents and discusses the findings. Finally, Section 5 presents the final considerations.

2. Theoretical and Empirical Bases

2.1 Related literature

Some articles study the relationship between the areas of agriculture and climatology (Bush, 2010). A subset of these studies deals with the effect of weather variables on the behavior of the stock market (Symeonidis *et al.*, 2010; Murphy *et al.*, 2012). Keef & Roush (2002) relate daily returns of the stock market in New Zealand and information about the weather. The authors argue that the effect of swings in weather variables, such as temperature and wind, on stock returns depends on the specific location of the investor, and that wind has a negative influence on returns.

Kang *et al.* (2010) study the effect of the weather on the return and volatility of the financial market in Shanghai. The authors conclude that temperature has a negative effect on the return for domestic investors, but has no effect on foreign investors. This result is in line with the study of Keef & Roush (2002), which emphasizes the importance of the geographic location of the investor on the stock returns. However, the volatility of the financial market in Shanghai suffers an impact due to swings in rainfall and temperature both for local and foreign investors.

Using data from countries in Asia, Europe and North America, Cao & Wei (2005) find that the returns of the respective stock exchanges are negatively associated with temperature. Levy & Galili (2008) state that the significance of the weather effect on the financial market in Israel, generally speaking, depends on the type of investor (institutional or individual). The studies of Shu (2008) and Chang et al. (2008), which analyze the effect of weather on the Taiwanese market, corroborate this result. Chang *et al.* (2008) also analyzing the effects of humidity and cloud cover and state that returns on the stock market in Taiwan are generally smaller on cloudy days (with extensive cloud cover).

Using weather data from the city of New York and stocks traded on the New York Stock Exchange (NYSE), Trombley (1997) concludes that the impact of climate change on the North American stock exchange varies over time.[4] Chang *et al.* (2008) also examine the relationship between climate change and the NYSE and conclude that the impacts of rainfall and temperature are only significant when the market opens. However, Akhtari (2011) stresses that this investigated relationship between weather and the stock market in New York does not depend on the time of day the trading occurs, but that there is a cyclical weather pattern effect on the NYSE stock exchange throughout the year.

Hirshleifer & Shumway (2003) examine the behavior of the stock returns on sunny days for 26 stock exchanges in the period between 1982 and 1997. The authors indicated that a greater incidence of sun's rays (sunny days) is significantly correlated with the daily stock returns.

In a more general context, Prodan (2013) argues that the significance of the weather effect depends on a series of factors, among which: i) the definition of the weather variables; ii) the type of investor; iii) the location of the companies being analyzed; and iv) the procedure and statistical test used in the research. Therefore, the different conclusions being reached from similar research may be explained by the variability of these factors. This argument is relevant, since we limit our work to Brazilian food companies and the 'rainfall' weather variable, and because of the fact that we do not deal with the type of investor in each company.

Using temperature and rainfall data from 329 weather stations and wheat production data in Europe, Iglesias *et al.* (2000) studied seven producing regions in Spain. Based on a spatial analysis, the authors found that an increase in temperature and a reduction in rainfall have a negative effect on wheat production. Considering various industrial sectors in Germany, Bergmann *et al.* (2016) state that extreme weather events affect the capacity of companies to obtain growth in sales.

[4] Saunders Jr. (1993) had already pointed to a systematic effect of local weather conditions on the price of stocks traded on the NYSE.

The magnitude of the predicted impact of climate change on food production in Africa varies widely between studies. In this respect, Challinor *et al.* (2007) claim that most of the studies on Africa indicate the negative impact of climate change on food productivity, which can lead to an increase in prices. They also state that governments should put into practice better institutional and macroeconomic conditions that help companies adapt to climate change at the local, national and transnational levels.

This argument is supported by Swan *et al.* (2010), who analyze the impact of the variation in food prices in Africa. The authors emphasize how important it is for governments to plan adequate interventions in order to protect the means of subsistence, due to the effects of the increase in food prices. Along the same line of thinking, Bush (2010) explores the phenomenon of disruptions to food supply unleashed by price peaks in Africa at the time of the financial crisis of 2007-2008.

Thornton *et al.* (2010) develop simulations for two widely-grown crops in Africa, corn and beans, and identify that climate change affects African agricultural production in a significantly negative way. Rosenzweig *et al.* (2001), using food and weather data from Latin countries, suggest that food production is directly sensitive to temperature increases and rainfall reductions. A similar result is presented in Defeo *et al.* (2013), whose argument points out that climate change has a long-term effect on small scale fishing.

Sietz *et al.* (2012) claim that small farmers in Peru are threatened by the possible occurrence of droughts, frosts and heavy rain. The authors state that climate change is affecting the food security of that country in terms of food production and availability. This study corroborates the work of Vörösmarty *et al.* (2013), which states that the rural population of South America is more sensitive to extreme rainfall than the urban population.

Jones & Thornton (2003) studied the possible impacts of climate change on corn production in Latin America and Africa. The results suggest that there is a 10% reduction in corn production in these regions, which is the equivalent of losses of US$ 2 billion per year. The authors also stress that climate change needs to be assessed within a family context, so that the poorest and most vulnerable people who are dependent on agriculture can receive suitable advice and guidance, with the objective of reducing poverty (Parry *et al.*, 1999; Vörösmarty *et al.*, 2013).

Using data from Latin America and the United States, Murphy *et al.* (2012) analyzed the importance of instruments for managing risks associated with food price volatility and the risk of climate change, since extreme weather events will tend to become more frequent in the future and, as a result, the risks and uncertainties in the global food system may increase (Wheeler & von Braun, 2013). The analysis of the effect of risk management on grain producers in the United States is discussed in Cornaggia (2013). This author found out that hedge operations improve productivity by lessening the financial restrictions of agricultural producers.

2.2 Risk and Extreme Value Theory

In the present study the share prices of Brazilian companies from the food industry is evaluated using the occurrence of extreme rainfall. To find out if there are extremely negative returns when these weather events are present we use the Extreme Value Theory (EVT). The procedure consists in calculating the value at risk (VaR) using the EVT based on returns that are adjusted by an AR-GARCH model and observing if the negative stock return after a day of extreme rainfall is greater (in module) than the VaR.

The VaR methodology was initially used to control the internal risk of financial institutions. It estimates how much a trading portfolio might lose, given normal market conditions, in a set period such as a day. Kuester, Mittnik & Paolella (2006) document an extensive and detailed review and make comparisons between various alternative methodologies for estimating the VaR. Among the various existing methodologies, the EVT is recommended for statistically analyzing events that are highly improbable. In other words, EVT is usually used for analyzing the maximum or minimum values of a random variable, order statistics or values that exceed a certain threshold (Embrechts *et al.*, 1997).

In this work, we consider the 'peaks over thresholds' approach and parametric models. In considering a random variable X over a certain threshold u and defining the variable $Y = X - u$, the GPD distribution can be represented as follows:

$$W_{\xi,\delta}(Y) = 1 - (1 + \xi Y/\delta)^{-1/\xi} \quad (1)$$

where δ and ξ correspond to scale parameters and the tail density of the GPD distribution, respectively.

To implement the EVT, the standardized residuals were ordered in order statistics: $z_{(1)}, ..., z_{(n)}$. Therefore, the distribution given in (1) was adjusted to the excess residuals over the threshold $z_{(k+1)}$, i.e., to the data ($z_{(1)} - z_{(k+1)}, ..., z_{(k)} - z_{(k+1)}$), where k corresponds to the number of data in the tail of the distribution. So the $\hat{z}_q$ quantile estimated for the tail of the distribution is given by (2) (McNeil & Frey, 2000):

$$\hat{z}_q = z_{(k+1)} + (\hat{\delta}_k/\hat{\xi}_k)((\frac{1-q}{k/n})^{-\hat{\xi}_k} - 1) \qquad (2)$$

in which n is the total number of data (standardized residuals) and q is the quantile of the distribution associated with the losses. Finally, the VaR was estimated in the way shown in (3):

$$\widehat{VaR}_{i,q} = \hat{\mu}_{i,t+1} + \hat{\sigma}_{i,t+1}\, \hat{z}_{i,q} \qquad (3)$$

where: $\hat{\mu}_{i,t+1}$ is the estimate of the conditional mean of the returns of the AR(1) model and $\hat{\sigma}_{i,t+1}$ is the estimate of the conditional volatility of the GARCH process (1,1), of share i on day $t+1$. As the daily stock returns are adjusted using an AR-GARCH model and the estimated VaR is based on standardized residuals, the basis of which is the EVT using the generalized Pareto distribution, we can say that the calculation of the VaR is estimated based on an AR-GARCH-GPD model.

3. Empirical Strategy

As Chesney *et al.* (2011) argue, a study of the possible impact of extreme events on the behavior of share prices may be conducted by way of a comparison of the stock return observed on the day after the extreme event, with the value at risk (VaR) estimated for this day and computed using different confidence levels. When extreme rainfall occurs, if the negative return on the share observed on the day after the extreme event is greater (in module) than the respective estimated VaR, the conclusion is that this particular extreme rainfall event has a significant impact on the return on the share being analyzed (Chesney *et al.*, 2011).

Formally, considering t to be the day on which the extreme rainfall occurred, i.e., a day when the rainfall exceeded 50mm; $R_{i,t+1}$ to be the financial return on share i on day $t+1$; and $\widehat{VaR}_{i,t+1}$ to be the estimated value at risk for day $t+1$, therefore, if $R_{i,t+1} < -\widehat{VaR}_{i,t+1}$, then the event that occurred on day t is considered to have had a significant impact on the financial return of the share being evaluated.

3.1 Data

With the objective of checking whether the occurrence of extreme rainfall has impact on companies of the Brazilian food industry, we used daily closing prices in *reais* (R$) of the stocks of food companies. In January 2015, there were 16 companies in the food sector listed on the Brazilian stock exchange, split into five segments: agriculture, coffee, meat and meat derivatives, grain and dairy products.

According to these segments, and with the aim of achieving greater robustness for adjusting the models, the criteria used for selecting the companies' stocks were: i) the extent; ii) liquidity; iii) regularity; and iv) consistency of the financial series. Furthermore, only companies that were still publicly quoted on the stock exchange on 12/30/2014 were considered.

Therefore, companies for which there was missing or inconsistent information in the database, or that had no share price data before 12/30/2014, were not considered in the sample. Companies that presented financial data with fewer than 1300 observations were also not used due to the maximum size of the observation windows (1000 days) used for estimating the AR-GARCH models.

The initial date for each share corresponds to the day the company first went public on the Brazilian stock exchange and the cut-off date was 12/30/2014 for all companies. Hence, the intervals of time for analyzing each share were different. In accordance with the choice criteria, only six of the sixteen listed companies were selected, as shown in Table 1 below.

Table 1: Brazilian Food Industry Companies Analyzed

Company	ISIN	Code	Industry	NAICS	Date[a]	Value (US$Mi)[b]
Renar Maçãs S.A.	BRRNARACNOR6	RNAR3	Agriculture	111331	2/28/2005	9.26
SLC Agrícola S.A.	BRSLCEACNOR2	SLCE3	Agriculture	111191	6/15/2007	526.21
Vanguarda Agro S.A.	BRVAGRACNOR2	VAGR3	Agriculture	111191	11/21/2006	206.86
Minerva S.A.	BRBEEFACNOR6	BEEF3	Meat & Derivatives	112111	7/19/2007	556.64
BRF Brasil S.A.	BRBRFSACNOR8	BRFS3	Meat & Derivatives	112111	5/19/2009	20,886.68
JBS S.A.	BRJBSSACNOR8	JBSS3	Meat & Derivatives	112111	3/28/2007	12,441.06

Note: Information obtained from the *Brazilian stock exchange*. [a]Initial closing date of the share price. [b]Market value of the companies on 12/30/2014 (in millions of dollars). Dollar quotation on 12/30/2014, R$ 2.65.

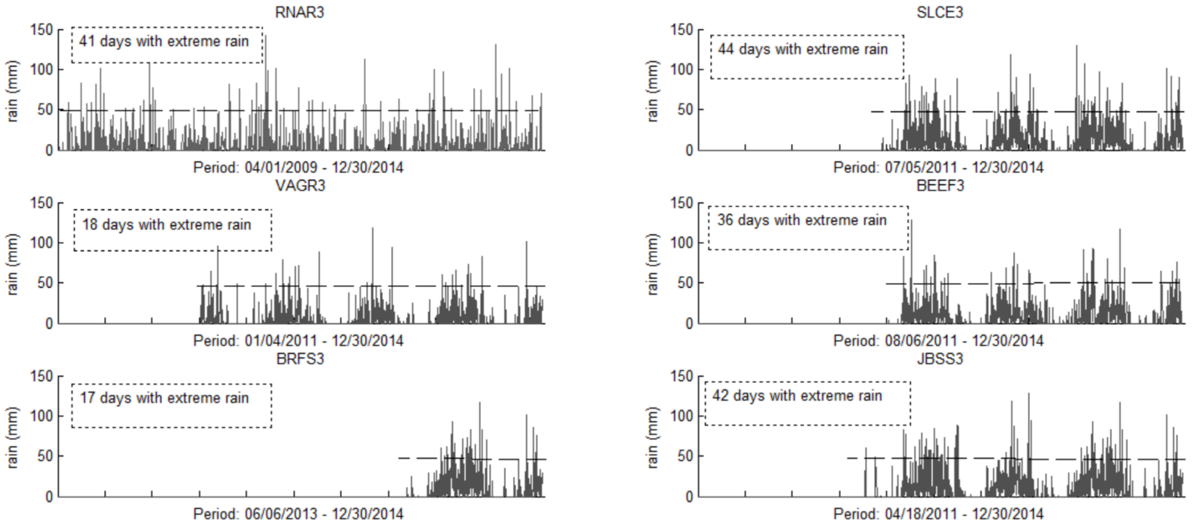
For assessing the impact of rainfall on stock returns of food companies, daily rainfall data were collected in the main regions where the companies operate, in accordance with the procedure recommended by Pérez & Yun (2013) and Prodan (2013). These rainfall figures in Brazil were collected from the Brazilian Meteorology Institute (*INMET*), an official Brazilian body linked to the Brazilian Ministry of Agriculture.

After checking the geographic position of the main region in which each of the companies operates, we accessed the website of the Meteorological Database for Teaching and Research (*BDMEP*) of *INMET* (*BDMEP*, 2015) to identify the weather-monitoring stations closest to these regions (Prodan, 2013). Based on this, daily rainfall data were collected according to the time intervals analyzed for each company selected. It is worth stressing that the *BDMEP* database is in accordance with the international standards of the World Meteorological Organization (*BDMEP*, 2015).

For companies that operate in more than one geographical region we considered the maximum daily rainfall figures of the closest respective meteorological stations to investigate only days of extreme rain (daily rainfall over 50 mm). In this way, it is possible to capture the effect of extreme rain in the different locations where each company operates.

Figure 1 shows the daily rainfall in the main regions in which the six companies studied operate.

Figure 1: Daily rainfall in the period analyzed



Note: daily rainfall (mm). The initial date of each series begins 1000 days after the company went public. The final date is 12/30/2014 and is the same for all series. The horizontal dashed line corresponds to 50 mm of rainfall in the day. The x axis corresponds to the daily observations and the y axis corresponds to the quantity of daily rainfall.

Because we used windows with up to 1000 daily price observations from adjusting the models, the initial date of each rainfall series starts 1000 days after each company analyzed went public. The final date is always 12/30/2014. In addition to the rainfall impact, idiosyncratic company events and systematic happenings could affect the stock prices (Cutler *et al*, 1989). However, as these events are not correlated to rain, we believe that if a large number of observations exceed the VaR, we can state that extreme rainfall has a negative impact on returns.

3.2 Model

Since this study concentrates on evaluating the occurrence of extreme impacts on stock prices, the methodology used refers to the adjustment of the distribution tail of the financial series, while ignoring the not-very-informative nature of the center of the distribution. Consequently, this adjustment requires a structured procedure for estimating the VaR in such a way that its predictive performance is accurate (Mendes, 2000).

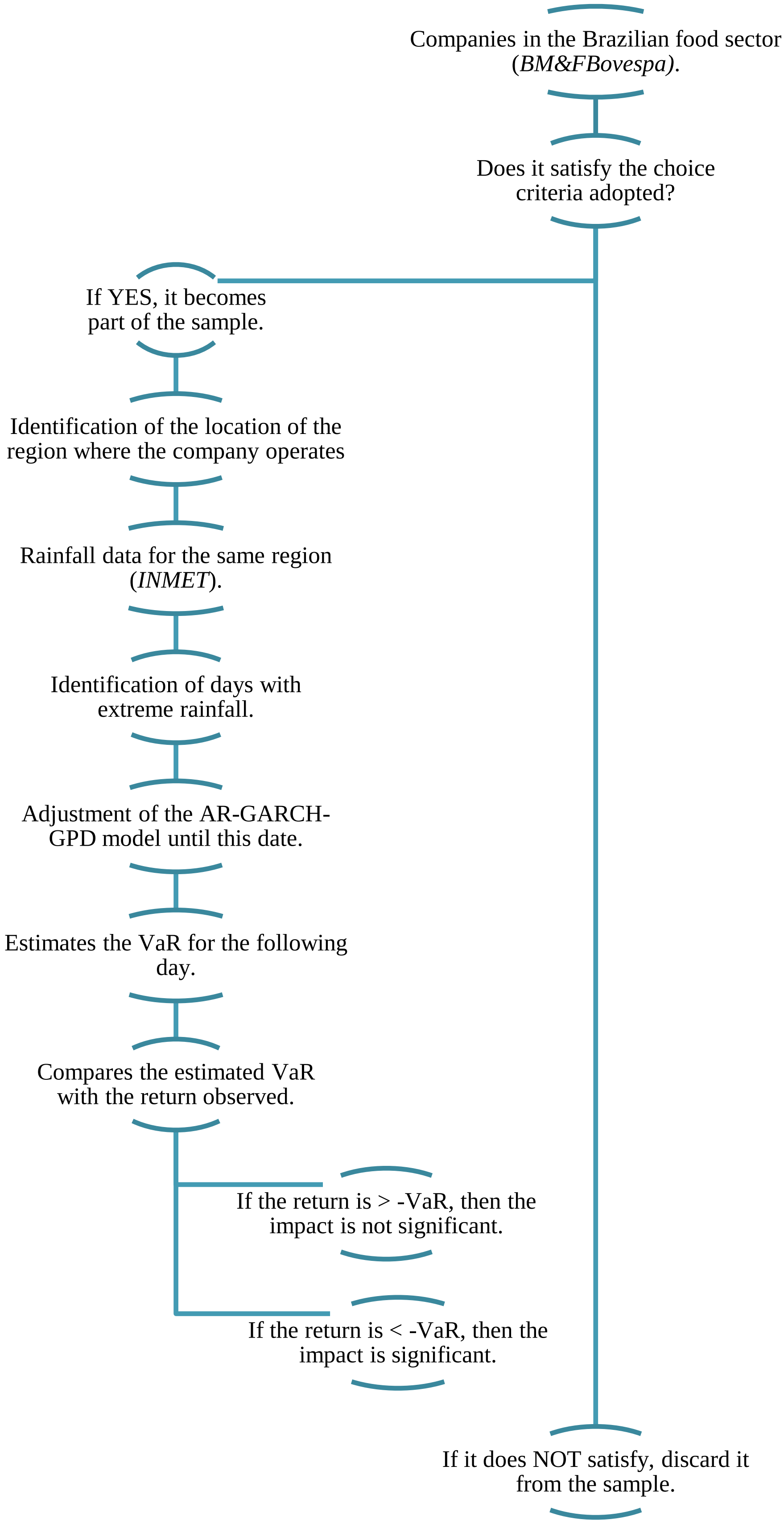
As financial series generally are temporally dependent and tend to exhibit volatility clusters, the distribution of the financial returns in the VaR calculation is adjusted using a GARCH-EVT approach (McNeil & Frey, 2000). This type of approach is also supported by Kuester et al. (2006), who show that the GARCH-EVT hybrid method performs in a superior way to other methods, such as GARCH-Normal and GARCH-t-Student. There are other researches into VaR estimates using the GARCH and EVT approach, including the studies of Longin (2005), Bali, Mo & Tang (2008), Zhao et al. (2010) and Karmakar (2013).

In this study, the autoregressive model AR (1) is adjusted to the return series with the idea of eliminating serial auto-correlation between observations. The residuals of the AR (1) model are adjusted by a GARCH (1,1) – Normal model due to its conditional heteroskedasticity. Consequently, the standardized residuals of this AR-GARCH model, in general, no longer present volatility clusters and temporal dependence, as required by the EVT for adjusting the GPD (Mendes, 2000). Therefore, these standardized residuals are adjusted by the generalized Pareto distribution (GPD) to obtain the VaR. We did not use orders greater than those of the AR(1)-GARCH(1,1) model for parsimony and effectiveness, as documented in McNeil & Frey (2000).

With regard to the rainfall data in the main region where each company operates, we identified the days on which extreme rains (daily rainfall > 50mm, according to Muniz *et al.* (2014)) occurred. On each of the identified extreme day, we considered observation windows corresponding to the historic daily stock log-returns up to the day of this extreme event.

Sub-samples with 500, 750 and 1000 historic daily observations were used for adjusting the AR(1)-GARCH(1,1)-GPD models for estimating the VaR for the day after the extreme event and comparing it with the series return. For the working methodology to be clearer, we constructed a flowchart (Figure 2) with the whole procedure adopted.

Figure 2: Flowchart of the Procedure Used



4. RESULTS

Table 2 shows the main descriptive statistics of the daily series of log-returns of each stock of the six companies analyzed. We can see in Table 2 that the daily means of all stock returns are close to zero and the skewness and kurtosis measures point to the non-normality of the series, which is ratified by the Jarque-Bera statistic, which was significant for all stocks analyzed at 1%.

Table 2: Descriptive Statistics of the Log-Returns Series

	Stocks analyzed					
	RNAR3	SLCE3	VAGR3	BEEF3	BRFS3	JBSS3
Mean	-0.00071	0.000051	-0.00211	-0.00025	0.001001	0.000189
Standard deviation	0.042	0.030	0.038	0.027	0.017	0.034
Kurtosis	11.84	14.42	19.24	3.09	2.03	4.51
Skewness	1.46	0.14	1.89	0.03	0.15	-0.08
Minimum	-0.24877	-0.24675	-0.17271	-0.17306	-0.07380	-0.25169
Maximum	-0.43410	0.32528	0.43146	0.12391	0.092910	0.24066
Jarque-Bera	6.49***	16.07***	31.93***	729.14 ***	241.94***	16.19 ***
N	2421	1866	2004	1842	1391	1919

Note: Descriptive statistics calculated from the daily log-returns series for each share *i*. Jarque-Bera corresponds to the Jarque-Bera statistic for testing the null hypothesis of normality of the series. *N* corresponds to the total number of daily observations for each share. ***, **, *, represent 1%, 5% and 10% significance, respectively.

Bearing in mind the aim to identify the impact of extreme rainfall and its magnitude using the methodology presented, the VaRs were calculated (with confidence intervals of 90%, 95% and 99%) for the day after the one on which the extreme event occurred.[5] At the three levels of confidence and in each sub-sample (500, 750 and 1000 observations), the estimated VaR was stable, as also reported in Karmakar (2013).

Using each VaR estimate found, the log-returns that occurred on the day after the extreme rainfall were analyzed and compared with the respective predicted VaR. In cases in which the negative log-returns were greater in module than the estimated VaR, the extreme events were considered to have a significant impact on the stock returns (Chesney et al., 2011).

[5] The day after the event (and not the day itself) was considered since we do not know the time the rain occurred on the day. This accumulation of rain may have occurred in periods after the stock exchange closed, for example, or at isolated moments during the day.

To identify those extreme events that were considered significant, the AR-GARCH-GPD model was re-estimated every day. Therefore, there is a different VaR model for each extreme event in each sub-sample (500, 750 and 1000 observations) and for each level of confidence (90%, 95% and 99%). In this article, the only results shown are of the level of confidence 95% and for the 1000 observations sub-sample as these specifications are the best that fit the VaR by the Kupiec Test (Kupiec, 1995). The results obtained are reported in Table 3.

Table 3: Impact of Extreme Rainfall

	RNAR3	SLCE3	VAGR3	BEEF3	BRFS3	JBSS3
Initial date[(a)]	04/01/2009	07/05/2011	01/04/2011	08/06/2011	06/06/2013	4/18/2011
Final date[(b)]	12/30/2014	12/30/2014	12/30/2014	12/30/2014	12/30/2014	12/30/2014
# extreme events[(c)]	41	44	18	36	17	42
# impacts[(d)]	15	23	10	20	13	22
% Impact[(e)]	36.59%	52.27%	55.56%	55.56%	76.47%	52.38%
Magnitude[(f)]	3.41%	1.49%	1.70%	1.99%	0.66%	2.59%

Note: Estimated model for 1000 observations with a 95% confidence level. [(a)] The initial analysis date for checking extreme rainfall was considered to start 1000 days after the first log-return observed for each share. This is to enable an initial sample of up to 1000 observations for estimating the VaR. [(b)] Last day of observations. [(c)] Number of days on which extreme rainfall occurred in the period analyzed. [(d)] Number of days on which there was a significant impact. [(e)] Number of days (in percentages) with impacts considered to be significant. [(f)] Average daily loss calculated for the days on which there were significant impacts.

Table 3 shows that in the period analyzed (between 4/18/2011 and 12/30/2014) there were 42 days with extreme rainfall in the main region in which JBS operates. Of this total, from the methodology developed in this study, 22 occurrences (52.38% of the total) had a significant impact on the return on the share, the average loss of which was 2.59% on the day after the extreme event. Therefore, JBS stocks lost, on average, approximately US$ 322 million of its market value because of extreme rainfall.

In addition, we can note that the number of days with extreme rainfall in absolute terms was less for BRF (17 events), since the interval of time considered for analyzing BRF was less than for the others. However, in relative terms we can observe that approximately 76.5% of the days with extreme rainfall had a significant impact on the return on BRF's share.[6] The size of the impact due to extreme rainfall is the smallest of the six stocks analyzed (average daily loss of 0.66%). Since BRF and JBS together have

[6] This result is relevant since this company is one of the biggest in the country. The participation of the BRF share in the Brazilian stock exchange's most important index, *IBOVESPA*, is 3.47% (April 2015 value; see *BM&FBovespa*, 2015a).

an expressive participation in the *IBOVESPA* (around 6.5% in April 2015), these results may become relevant to investors that follow this benchmark.[7]

BRF shows its concern with climate change in its financial statements, but it holds no position in weather derivatives. The company only hedges the price of agricultural commodities, regarding that the main inputs of its production originate from grains, soybeans and corn (*BM&FBovespa*, 2015b). By way of illustration, we show an example of an observation in which there was a significant impact caused by extreme rainfall: On February 12, 2014, 60 mm of rain ocurred in the main region where BRF operates. The $VaR_{99\%}$ was estimated at 0.58% for 2/13/2014. The loss incurred by BRF's share on 2/13/2014 was 0.6255%, which represents a loss of approximately US$ 131 million of its market value. This loss may be linked to other factors, but if the negative return on the share exceeds the VaR on various occasions when there is extreme rainfall, this is an evidence that this event is having an impact on the share price. JBS, which is in the same sub-sector as BRF, had approximately 52.4% significant impacts on its returns in the period analyzed and had a sizeable expected loss of 2.59% on the day after the extreme rain event.[8]

Despite BRF and JBS being from the same sub-sector, the impacts arising from extreme rainfall and its effects proved to be different in terms of their stock returns. This may arise from different factors, such as: i) the companies operate in different regions; ii) the existence of different intervals of time being analyzed (Trombley, 1997); and iii) the types of investors in the stock of these companies (Levy & Galili, 2008). This analysis is supported by Keef & Roush (2002), who state that the weather impact depends on the specific region in which each company operates.

Minerva had approximately 55.6% days of extreme rainfall that had an impact on their returns. In other words, more than half of the days that had rainfall in excess of 50 mm had a negative impact on the financial return of their stock. SLC Agrícola and Vanguarda Agro had around 54% significant impacts and expected losses were close to 1.5% on the day after the extreme rainfall. As these two companies focus more on producing agricultural commodities (cotton, soybeans and corn), rain can lead to delays

[7] The *IBOVESPA* is the main Brazilian stock market index.
[8] JBS had a 3.02% participation in *IBOVESPA* in April 2015.

in harvesting or even affect the quality of the grains (*BM&FBovespa*, 2015c; *Embrapa*, 2015).

Renar Maçãs, which produces apples, had a significant impact from extreme rainfall that was smaller (around 36.5%) than with the other companies analyzed. However, the size of the expected loss impact (3.41%) was the biggest among the six stocks analyzed. Because its production is all concentrated in a single city, this company is the most vulnerable to the occurrence of rain (Sietz et al., 2012).

Since the periods assessed are different for each stock and the locations are different between companies, the impacts of extreme rainfall vary between the stocks analyzed. These findings are in line with those of Vermeulen, *et al.* (2012), who find that the impact of climate change on the food system tends to be temporally and geographically variable around the world.

Based on these results, we can state that there is evidence that the occurrence of extreme rainfall has a significant impact on the stocks of Brazilian food companies. The impact is not irrelevant: the daily average size of loss of the stocks analyzed was 1.97%, which in terms of market value represents an average loss of approximately US$ 682.15 million in a single day for only six companies.

Murphy et al. (2012) state the importance of using weather risk management instruments in Latin America, where they are still just in the beginning. Since the companies analyzed had no positions in weather derivatives, the results of this work corroborate Murphy *et al.* (2012). In other words, the results show how important it is for companies in the food sector in Brazil to use rain derivatives as a way of controlling risks arising from extreme rainfall.

5. Concluding Remarks

The main source of uncertainty in agricultural production is the weather (Musshoff, Odening & Xu, 2011). In addition, World-Bank (2015b) states that food production is threatened by a series of factors, among them extreme weather events (World-Bank, 2015b). Moreover, food security is an important subject for food industry firms, for portfolio managers, for governments and especially for society (World-Bank, 2014). The aim of this article is to study the impact of extreme weather events on food industry companies in an emerging economy that is a major global player in this sector, Brazil.

We analyze the stocks of six companies from the Brazilian food sector listed on the Brazilian stock exchange. For this purpose, we used the AR-GARCH-GPD model. First the log-returns of the individual financial series of the stocks were adjusted using the AR(1)-GARCH(1,1) models. Then, we used the innovations generated by the models and the extreme value theory to estimate the 95%-VaR (VaR with 95% level of confidence) when the rainfall is extreme. The extreme value theory method used is the parametric approach with the hypothesis that the distributions of the tails follow the generalized Pareto distribution (GPD). If the negative return of the company (in absolute value) in a day immediately after the extreme rain is lower than the VaR, the conclusion is that the extreme rainfall had a significant impact on the stock return.

The results indicate that in five out of the six stocks analyzed more than 50% of the extreme rainfall had a significant impact on the stock returns. For the remaining company, significant extreme impacts reached 36.59%, but the size of the loss on the day after the extreme rainfall event was the biggest (3.41%) among the companies analyzed.

We can conclude that the Brazilian food industry is significantly affected by extreme rainfall. These results are important for encouraging Brazilian companies to use weather derivatives. The results also provide support for creating and offering rainfall derivative contracts by the Brazilian stock exchange, already offered in developed economies.

References

Akhtari, M. (2011). Reassessment of the weather effect: Stock prices and wall street weather. *Undergraduate Economic Review*, *7*(1), 51–70.

Bali, T. G., Mo, H. & Tang, Y. (2008). The role of autoregressive conditional skewness and kurtosis in the estimation of conditional var. *Journal of Banking & Finance*, *32*(2), 269–282.

Bergmann, A., Stechemesser, K. & Guenther, E. (2016). Natural resource dependence theory: Impact of extreme weather events on organizations. *Journal of Business Research*, 69(4), 1361–1366.

BDMEP. (2015). *Banco de dados meteorológicos para ensino e pesquisa do inmet.* http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep. (Acessado em 05 de janeiro de 2015).

BM&FBovespa. (2015a). *Bm&fbovespa a nova bolsa.* http://www.bmfbovespa.com.br/ (Acessado em 10 de abril de 2015).
BM&FBovespa. (2015b). *Bm&fbovespa a nova bolsa.* http://www.bmfbovespa.com.br/shared/iframe (Acessado em 25 de agosto de 2015).
BM&FBovespa. (2015c). *Bm&fbovespa a nova bolsa.* http://www.bmfbovespa.com.br/cias-listadas/empresaslistadas/ Resumo Empresa Principal. (Acessado em 02 de maio de 2015).
Bush, R. (2010). Food riots: Poverty, power and protest. *Journal of Agrarian Change*, *10*(1), 119–129.
Cabrera, B. L., Odening, M. & Ritter, M. (2013). Pricing rainfall futures at the cme. *Journal of Banking & Finance*, *37*(11), 4286–4298.
Cao, M., & Wei, J. (2005). Stock market returns: A note on temperature anomaly. *Journal of Banking & Finance*, *29*(6), 1559–1573.
CEPEA. (2015). *Centro de estudos avançados em economia aplicada.* http://cepea.esalq.usp.br (Acessado em 12 de fevereiro de 2015).
Challinor, A., Wheeler, T., Garforth, C., Craufurd, P. e Kassam, A. (2007). Assessing the vulnerability of food crop systems in Africa to climate change. *Climatic change*, *83*(3), 381–399.
Chang, S.-C., Chen, S.-S., Chou, R. K. & Lin, Y.-H. (2008). Weather and intraday patterns in stock returns and trading activity. *Journal of Banking & Finance*, *32*(9), 1754–1766.
Chang, T., Nieh, C.-C., Yang, M. J. & Yang, T.-Y. (2008) Are stock markets returns related to the weather effects? Empirical evidence from Taiwan. *Physica A: Statistical Mechanisms and its Applications*, 364, 343–354.
Chavez-Demoulin, V., Embrechts, P. & Sardy, S. (2014). Extreme-quantile tracking for financial time series. *Journal of Econometrics*, *181*(1), 44–52.
Chesney, M., Reshetar, G. & Karaman, M. (2011). The impact of terrorism on financial markets: An empirical study. *Journal of Banking & Finance*, *35*(2), 253–26
Cornaggia, J. (2013). Does risk management matter? Evidence from the US agricultural industry. *Journal of Financial Economics*, *109*(2), 419–440.
Cutler, D. M., Poterba, J. M. & Summers, L. H. (1989). What moves stock prices? *The Journal of Portfolio Management*, *15*(3), 4–12.
Defeo, O., Castrejón, M., Ortega, L., Kuhn, A. M., Gutiérrez, N. L. & Castilla, J. C. (2013). Impacts of climate variability on Latin American small-scale fisheries. *Ecology and Society*, *18*(4), 30.
Embrapa. (2015). *Empresa brasileira de pesquisa agropecuária.* https://www.embrapa.br/publicacoes (Acessado em 02 de maio de 2015).
Embrechts, P., Klüppelberg, C. e Mikosch, T. (1997). *Modelling extremal events* (Vol. 33). Springer Science & Business Media.
Gnedenko, B.V. (1943). Sur la distribution limite du terme maximum d'une série aléatoire. *Ann. of Math*., 44, 423–453.Ghosh, J. (2010). The unnatural coupling: Food and global finance. *Journal of Agrarian Change*, *10*(1), 72–86.
Hirshleifer, D. & Shumway, T. (2003). Good day sunshine: Stock returns and the weather. *The Journal of Finance*, 58(3), 1009–1032.
Iglesias, A., Rosenzweig, C. & Pereira, D. (2000). Agricultural impacts of climate change in Spain: Developing tools for a spatial analysis. *Global Environmental Change*, *10*(1), 69–80.

Jones, P. G., & Thornton, P. K. (2003). The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global environmental change*, *13*(1), 51–59.

Kang, S. H., Jiang, Z., Lee, Y. & Yoon, S.-M. (2010). Weather effects on the returns and volatility of the Shanghai stock market. *Physica A: Statistical Mechanics and its Applications*, *389*(1), 91–99.

Karmakar, M. (2013). Estimation of tail-related risk measures in the indian stock market: An extreme value approach. *Review of Financial Economics*, *22*(3), 79–85.

Keef, S. P., & Roush, M. L. (2002). The weather and stock returns in New Zealand. *Quarterly Journal of Business and Economics*, 61–79.

Kuester, K., Mittnik, S. & Paolella, M. S. (2006). Value-at-risk prediction: A comparison of alternative strategies. *Journal of Financial Econometrics*, *4*(1), 53–89.

Kupiec, P. H. (1995). Techniques for verifying the accuracy of risk measurement models. *The Journal of Derivatives*, *3*(2), 73–84.

Levy, O., & Galili, I. (2008). Stock purchase and the weather: Individual differences. *Journal of Economic Behavior & Organization*, *67*(3), 755–767.

Longin, F. (2005). The choice of the distribution of asset returns: How extreme value theory can help? *Journal of Banking & Finance*, *29*(4), 1017–1035.

Marengo, J., Jones, R., Alves, L. & Valverde, M. (2009). Future change of temperature and precipitation extremes in South America as derived from the prices regional climate modeling system. *International Journal of Climatology*, *29*(15), 2241–2255.

McNeil, A. J., & Frey, R. (2000). Estimation of tail-related risk measures for heteroscedastic financial time series: An extreme value approach. *Journal of Empirical Finance*, *7*(3), 271–300.

Mendes, B. (2000). Computing robust risk measures in emerging equity markets using extreme value theory. *Emerging Markets Quarterly*, *4*(2), 25–41.

Muniz, S., de Assis, J. M. O. & de Souza, W. M. (2014). Tendências de mudanças climáticas na bacia do rio una, pernambuco–brasil (trends of climate change on the una river basin, pernambuco–brazil). *Revista Brasileira de Geografia Física*, *7*(2), 243–257.

Murphy, A. G., Hartell, J., Cárdenas, V. & Skees, J. R. (2012). *Risk management instruments for food price volatility and weather risk in Latin America and the Caribbean: The use of risk management instruments* (Tech. Rep.). Inter-American Development Bank.

Musshoff, O., Odening, M. & Xu, W. (2011). Management of climate risks in agriculture–will weather derivatives permeate? *Applied Economics*, *43*(9), 1067–1077.

Parry, M., Rosenzweig, C., Iglesias, A., Fischer, G. & Livermore, M. (1999). Climate change and world food security: A new assessment. *Global environmental change*, *9*, S51–S67.

Pérez, F., & Yun, H. (2013). Risk management and firm value: Evidence from weather derivatives. *The Journal of Finance*, *68*(5), 2143–2176.

Prodan, I. (2013). *The effect of weather on stock returns: A comparison between emerging and developed markets*. Anchor Academic Publishing (aap_verlag).

Rosenzweig, C., Iglesias, A., Yang, X., Epstein, P. R. & Chivian, E. (2001). Climate change and extreme weather events; implications for food production, plant diseases, and pests. *Global change & Human Health*, *2*(2), 90–104.

Saunders Jr., E. M. (1993). Stock prices and Wall Street weather. *The American Economic Review*, 83(5), 1337–1345.

Scarrott, C., & MacDonald, A. (2012). A review of extreme value threshold estimation and uncertainty quantification. *REVSTAT–Statistical Journal*, *10*(1), 33–60.

Shu, H. (2008). Weather, investor sentiment and stock market returns: Evidence from Taiwan. *Journal of American Academy of Business*, *14*(1), 96–102.

Sietz, D., Choque, S. E. M. & Lüdeke, M. K. (2012). Typical patterns of smallholder vulnerability to weather extremes with regard to food security in the peruvian altiplano. *Regional Environmental Change*, *12*(3), 489–505.

Swan, S. H., Hadley, S. & Cichon, B. (2010). Crisis behind closed doors: Global food crisis and local hunger. *Journal of Agrarian Change*, *10*(1), 107–118.

Symeonidis, L., Daskalakis, G. & Markellos, R. N. (2010). Does the weather affect stock market volatility? *Finance Research Letters*, *7*(4), 214–223.

Thornton, P. K., Jones, P. G., Alagarswamy, G., Andresen, J. & Herrero, M. (2010). Adapting to climate change: Agricultural system and household impacts in East Africa. *Agricultural systems*, *103*(2), 73–82.

Trombley, M. A. (1997). Stock prices & wall street weather: Additional evidence. *Quarterly Journal of Business and Economics*, 11–21.

Vermeulen, S. J., Campbell, B. M. & Ingram, J. S. (2012). Climate change and food systems. *Annual Review of Environment and Resources*, *37*(1), 195.

Vörösmarty, C. J., de Guenni, L. B., Wollheim, W. M., Pellerin, B., Bjerklie, D., Cardoso, M., & Colon, L. (2013). Extreme rainfall, vulnerability and risk: a continental-scale assessment for South America. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, *371*(2002), 1–17.

Walter, A. (2007). As mudanças climáticas e a questão energética. *Revista Multiciência. Campinas. Edição*(8), 29–47.

Wheeler, T., & von Braun, J. (2013). Climate change impacts on global food security. *Science*, *341*(6145), 508–513.

World-Bank. (2014). World development report 2014: Risk and opportunity. managing risk for development.

World-Bank. (2015a). http://data.worldbank.org/country/brazil (Acessado em 10 de janeiro de 2015).

World-Bank. (2015b). *Por que o seu almoço está em risco?* http://www.worldbank.org/pt/events/2014/11/20/brazil-seminarevaluation-risks-agriculture (Acessado em 10 de abril de 2015).

Zhao, X., Scarrott, C., Oxley, L. e Reale, M. (2010). Extreme value modelling for forecasting market crisis impacts. Applied Financial Economics, 20(1-2), 63–72.