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Commodity market risk from 1995 to 2013: an extreme value theory approach

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In this article we examine whether extreme risk has increased in the agricultural commodity market during the period 1995–2013. We add to the literature on food price volatility by analysing the tail segment of futures price return distributions. Food price variability is a concern for governments and regulators worldwide, as most nations trade in food. High food price variability can contribute to poverty and malnourishment, in particular for people in less economically developed economies. We find no indications of systematically increasing tail-risk for the commodities in our sample. Analysis of estimated shape-parameters of the Generalized Extreme Value distribution further supports the conclusion that there is no general systematic change in the extreme risk associated with these commodity investments.

Keywords: tail risk; extreme value theory; generalized extreme value distribution; bootstrapping; agricultural commodities

JEL Classification: G1; G13; G15; Q110

I. Introduction

This study is a contribution to the debate on whether commodity prices have become more volatile during recent years. The previous decade has been characterized by significant turbulence in financial markets worldwide, and a lot of attention has been focused on commodities and the adverse effects of increasing food prices. The price volatility of agricultural commodities is a topic that has been under less scrutiny, and the majority of analyses have focused on traditional volatility measures such as variance and SD. Measuring dispersion around the mean can give a good gauge of movements around a trend or a central tendency, but fails to capture the risk associated with the extreme events that manifest themselves as outliers. Our contribution in this respect is an analysis of the tail risk related to commodity investments.

After more than 20 years of stagnant prices, agricultural commodity prices started to increase rapidly in 2006, peaking in July 2008. Soon thereafter prices plummeted, and remained low throughout the financial crisis before recovering in the second half of 2009 (see Fig. 1). By April 2011, prices were again approaching the levels preceding 2008. Both academics and regulators have been

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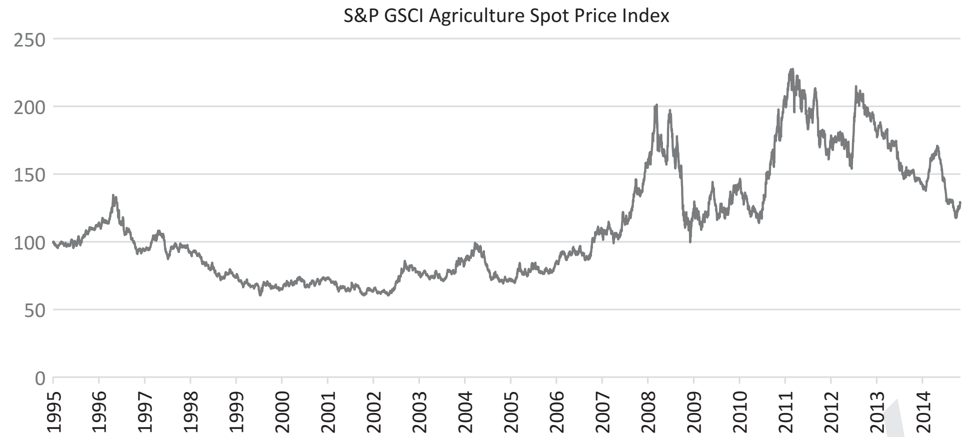

Fig. 1. The S&P GSCI agricultural spot price index, daily prices 02.01.95–31.10.14 (Rebased, 2 January 1995 = 100)

trying to identify the driving forces behind this upsurge in commodity prices.

Food price volatility will affect virtually all economies across the globe, as most nations trade in food (Gilbert and Morgan, 2010). The impact is determined by whether the country is a net importer or exporter of agricultural commodities, and to what degree it is integrated into world markets. Industrial countries are less exposed to volatility risk at the micro level, as households in more economically developed nations spend a lesser proportion of their disposable income on food. Moreover, producers in richer nations have more tools available to accommodate volatility risk, such as futures hedging in commodity markets or crop insurance. Developing countries are clearly more vulnerable to food price volatility because their trade bill is often heavily dependent on primary commodities. The net welfare effects hinge on whether the country is a net importer of food, or whether agricultural commodities are a source for export earnings. For instance, volatility in world soybean prices during the period 2007–2009 contributed to increased poverty in Indonesia, being a net importer of this commodity (Dartanto and Usman, 2011). People in poorer countries generally spend a large portion of the household income on food, and there are often few alternatives for staple food items (Gilbert and Morgan, 2010).

In this article we expand the existing body of literature on commodity price volatility by examining extreme price deviations, as opposed to deviations defined in terms of the normal distribution. This topic should be of both academic and practical interest as price variability influences a variety of financial decisions such as asset allocation, risk transfer and derivative pricing. It is well established that commodity price returns exhibit high peaks and excess kurtosis (Geman, 2005), which means that extreme deviations from the mean are more likely than what models and risk metrics based on the normal distribution imply.

Extreme events have been widely discussed in the aftermath of the financial crisis. Some argue that not only are such events much more common than predicted by modern financial theory, the consequences of extreme market moves are also largely underestimated. A problem with many tools in finance is that they attempt to capture the entire density of a distribution typically using SD, skewness and kurtosis. In practice, this means that we get a good description of the mean and central area where we have an abundance of data, but this approach fails in the tails where we have very few observations to go on. For these reasons, we choose to focus solely on the tail behaviour of commodity price returns in order to provide more information on price volatility in these markets, and whether price volatility changes during the period 1995–2013. Our theoretical approach is the extreme value theory (EVT), which has the advantage of utilizing the benefit of asymptotic results that hold for a wide range of parametric distributions. Further, EVT provides the possibility of focusing on the two tails of the distribution separately, which is appropriate when faced with skewed distributions.

In the next section, we discuss the rationale and theoretical foundation for this article. Section III presents data and descriptive statistics for nine agricultural commodities, observed daily from January 1995 through December 2013. In Section IV, we outline a methodological framework for risk assessment based on EVT. Section V gives an overview of our empirical findings, and Section VI contains concluding remarks.

II. Related Literature

Equities and bonds are valued by discounting expected future cash flows, and exist for the sole purpose of being investment vehicles. Commodities are different in that they exist to be consumed, and not to generate future returns. In that sense, they are not financial assets. A defining feature of commodities as an asset class is that they should not be valued by net present analysis (Greer, 1997; Geman, 2005). Instead, long-term commodity prices are determined by a combination of fundamental factors and the interaction of supply and demand. In the short run, price changes are driven by inflow of information to the market place, forming expectations and speculation regarding future supply and demand dynamics.

Fundamental factors

Typically, agricultural price booms and periods of high volatility are caused by shocks to the supply side. Weather events or animal diseases that disturb the normal pattern of variation that is expected in agricultural production are examples of such supply-side shocks. High and unexpected demand can also cause high prices and volatility spikes. During the crop year 1972–1973, Chicago wheat prices gyrated when the Soviet regime abandoned their policy of not trading with the capitalist world and instead bought 30 million metric tons of grain. This was more than half the commercially exported grain worldwide that season (Kub, 2012). The impact of supply and demand shocks on price volatility depends on the corresponding supply and demand elasticities. While it is difficult to get accurate elasticity estimates, it is generally agreed that commodity supply and demand are relatively inelastic, particularly within a crop season. Farmers cannot reap what they have not sown, and consumers are generally slow in terms of changing habitual food patterns. As previously mentioned, it can also be difficult to find alternative food staples in less developed economies.

Another key factor that affects agricultural prices and volatility is available inventory, worldwide or in a given region. In contrast to financial markets, volume risk is as crucial as price risk in commodity markets, because the quantity produced is not known with certainty *ex ante*. The theory of storage applies to all commodities that can be physically stored, and was brought forward by scholars like Keynes (1930), Working (1927, 1933, 1948, 1949), Kaldor (1939) and Brennan (1958). The theory makes two main predictions, where the first is that when the quantity held in inventory is low, spot prices will exceed futures prices, and spot price volatility will exceed futures price volatility. Conversely, when inventories are abundant, spot prices can become depressed with respect to futures prices, and volatility will be low.

Both 2007–2008 and 2010–2011 were characterized by adversely affected crops in several important regions for agricultural production (Trostle *et al.*, 2011). However, Gilbert (2010) argues that agricultural price booms are better explained by common factors, rather than market-specific factors like supply shocks. He highlights that demand growth, monetary expansion and exchange rate movements have been central explanatory factors of price movements since 1971. Monetary expansion and depreciation of the US dollar is also emphasized in Abbott *et al.* (2008) as driving the increase in agricultural prices. A good overview of macroeconomic factors that likely contributed to the price spike in 2008, is given in Pies *et al.* (2013). Here demand for food increased more rapidly than supply, together with subsequently declining stocks listed at the forefront.

Kilian (2009) demonstrates that rapid economic growth and industrialization in emerging Asia caused unexpected demand pressure that made energy prices gyrate around 2007–2008. Hamilton (2009) concludes that low demand price elasticity and strong growth in world demand were contributing factors to the increase in crude oil prices from 2006 through 2008. Both results are interesting, as a growing literature suggests that the correlation between energy and food prices is increasing – see, for instance, Gilbert (2010), Dorfman and Karali (2012), and Tang and Xiong (2012). Some authors attribute the strengthening of this linkage to the production of biofuel using corn as an input. Mitchell (2008) claims that the increase in biofuel production in the United States and the European Union was responsible for a large part of the build-up in food prices prior to the 2008 price spike. Rosegrant (2008) presents a similar conclusion in a testimony for the US Senate Committee on Homeland Security and Governmental Affairs. Likewise, Baffes (2011) discusses biofuel production, but downplays its role as a determinant of food prices during the last decade. His article highlights that biofuels only account for about 1.5% of the areas allocated to grains and oilseed crops worldwide, and shows that the correlation between biofuel production volume and maize/oilseed prices is very low. Nevertheless, the role of biofuels as a determinant of agricultural commodity prices and volatility remains controversial.

A thorough review of how biofuel policies might influence corn price volatility and price levels is given in Abbott (2013). The author concludes that increasing ethanol production has brought about a large, persistent and new demand for corn resulting in higher corn prices. He identifies a tighter linkage between energy and agricultural markets in some periods, but this effect is not constant. Finally, Abbott identifies switching regimes in terms of volatility levels, with short periods of surging volatility. This has led to a misperception of a permanent change in commodity price volatility levels, when in reality it was the big moves, especially around 2007–2008, which formed a false impression of lasting higher volatility levels. Baumeister and Kilian (2014) use impulse response analysis to disentangle the channels of transmission from the real price of oil to raw agricultural product prices, but find no evidence that the change in US biofuel policies in May 2006 have created a tighter link between oil and agricultural markets. Their analysis further shows that there is no systematic increase in food price volatility.

The role of speculation

Another widespread belief is that speculative influences, especially the growth of long-only index commodity funds, are driving commodity prices away from their fundamental levels. The debate on speculation and commodity price (in)stability has a long history (Jacks, 2007). For almost as long as we have had modern futures exchanges, a central issue has been whether futures trading stabilizes or destabilizes markets, where, in the latter case, it undermines the main reason for having such markets (Tomek and Gray, 1970; Peck, 1976). In a much debated paper, Pindyck and Rotemberg (1990) claimed some 20 years ago that commodity prices moved too much in parallel, indicating that herd behaviour rather than fundamentals was driving commodity prices.[1] This debate resurfaced during the commodity price boom in the period 2007–2008. A number of academic papers concluded that financial investors and speculators had turned commodities into financial assets decoupled from the fundamentals in, for instance, agricultural production. The increasing number of long-only commodity index trackers and the influx of large institutional investors and highly leveraged hedge funds in the commodity markets were said to cause excessive price surges (‘bubbles’) and dysfunctional markets. Two well-known papers in this category are Singleton (2011) – which found a statistically significant relationship between oil prices and investor activities in the market for oil futures[2] – and Tang and Xiong (2012), which found that commodity prices have become increasingly inter-correlated after 2005 and particularly so for commodities carrying weight in the most popular indices for index trackers. The authors argue that this means commodities have become ‘financialized’.

Irwin and Sanders dispute both the theoretical and empirical ground that futures market speculation is driving physical commodity prices (e.g. Irwin *et al.*, 2009; Irwin and Sanders, 2011, 2012). Likewise, Stoll and Whaley (2011) conclude that commodity index flows, whether due to rolling over existing futures positions or establishing new ones, have little impact on futures prices. The authors argue that owing to the passive and long-only nature of commodity index investments, these are unlikely culprits of inflated commodity prices. Steen and Gjølberg (2013) revisit Pindyck's herding hypothesis applying principal component analysis on a basket of 20 commodities. Examining monthly prices for the period 1986–2010, they find evidence of increased co-movements across commodities, and between

[1] This paper was later criticized for model misspecifications such as arbitrarily selected variables and failure to account for conditional heteroscedasticity; see, for instance, Deb *et al.* (1996) and Le Pen and Sévi (2013).
[2] This article has later been criticized for issues related to the data used in the analysis, as well as the interpretation of the results; see, for instance, Fattouh *et al.* (2012).

commodities and the stock market after 2004. The authors do, however, show that this result is mainly driven by the extreme price movements after 2008, and find no strong evidence of 'financialization', or contamination from the market activities of financial investors, prior to 2008.

There is also a growing body of literature that addresses the issue of increasing commodity market volatility. McPhail *et al.* (2012) study corn futures traded on the Chicago Board of Trade and use a structural vector autoregressive model and variance decomposition to analyse corn price volatility. The authors find that second to market-specific shocks for corn, speculation is the most important factor for explaining corn price variability in the short run. The other factors considered are global demand, energy prices and fuel policies. After six months, global demand becomes a more important explanatory factor relative to speculation, and after 12 months the influence of speculation on corn price volatility becomes negligible compared with the effects of global demand and energy prices. Algieri (2012) finds that (excess) speculation Granger causes changes in volatility for several agricultural commodities, but also notes that whether or not this finding is statistically significant depends on the selection of time windows. That the lead–lag dynamics of the two variables varies depending on the time period under consideration begs the question of whether or not the relationship is spurious. Tang and Xiong (2012) identify increasing co-movement in volatility returns for commodities by separating into yearly sub-periods using a regression-based approach. They find that commodities that are part of an index exhibit larger volatility increases relative to nonindex commodities in the years 2004, 2006–2009 and 2011. They argue that this is evidence that commodity prices no longer are determined solely by fundamental factors like supply and demand. The authors conclude that commodity markets are 'financialized', i.e. that commodity prices are affected by the investment behaviour of commodity index investors.

Several papers are unable to confirm that speculation has caused increasing commodity market volatility. Bastianin *et al.* (2012) examine energy and agricultural commodity futures markets and find that excess speculation is not relevant in explaining commodity return variability, with the exception of crude oil. Sanders and Irwin (2011) analyse the entire range of agricultural, energy, metal and soft commodity futures prices alongside index trader-position data. Cross-sectional Fama–McBeth regression tests reveal little evidence that index trader-positions influence commodity market return or volatility. While most studies of commodity price volatility focus on futures markets, Bohl and Stephan (2013) focus on how index investments might influence spot price volatility. Their study of six major agricultural and energy commodities fails to confirm a relationship between the share of noncommercial traders and commodity price variability. A similar conclusion is reached for futures prices in Bohl *et al.* (2013). The authors conclude that *'with respect to twelve increasingly financialized grain, livestock, and soft commodities, we do not find robust evidence that CITs*[3] *can be held responsible for making their futures prices more volatile'* (Bohl *et al.*, 2013, p. 15). AQ1

A more detailed literature survey of how financial speculation influences agricultural commodity prices can be found in Will *et al.* (2012). They conclude that there is little empirical evidence for the point of view that futures trading was the driving force behind the price spike in 2008, or that futures trading has caused increased commodity market volatility. Cheng and Xiong (2013) review academic studies of speculation in commodity markets, including energy and metals. They investigate how financial investors affect commodity prices through economic mechanisms, with emphasis on risk sharing and information discovery. The authors conclude that the influx of index investors has changed commodity markets through these channels.

III. Data

Because food price volatility is the main focus of this article, we have chosen to examine a broad range of agricultural commodities, namely corn, wheat, soybeans, soya oil, sugar, cocoa, orange juice, lean hogs and feeder cattle. The data cover front month futures prices from the Chicago Mercantile Exchange (CME) group. The CME group is the largest commodity options and futures exchange in the world, also providing markets for interest rates, equity indexes, foreign exchange, weather and real estate, in addition to a large number of commodities. It AQ2

[3] Commodity index traders.

forms a trading platform that includes the Chicago Mercantile Exchange, Chicago Board of Trade, Kansas City Board of Trade, New York Mercantile Exchange and New York Commodity Exchange (see www.cmegroup.com for more information regarding markets, product specifications, etc.). More details about the different contracts and where they are traded can be found in the Appendix. We choose to examine prices of nearby futures contracts since this market is forward looking by construction and respond rapidly to news and changes in expectations. Our analysis is based on continuous series of front month futures prices obtained from Datastream. The data is given as an index, which starts with base 100 representing the first price or the nearest contract month. Daily price returns from the front month contract is applied to the index until the contract reaches its expiry date. At this point the price returns from the next contract month is used. As the daily return from the index is consistent with the contract month, this effectively adjusts the index for rolling yield making this an excess return index. All return series are calculated as logs, and augmented Dickey–Fuller tests confirm that these series are stationary.

In Table 1, we have divided 18 years of daily observations into time periods of 5 years (the most recent period contains 3 years). The mean level of returns averages to zero over all periods and across all commodities, which is why we refrain from reporting these values here. All return distributions display moderate amount of skewness, which is natural as the commodity sector traditionally consists of both producers and consumers. As a consequence, the market is made up of participants that are concerned about both price rises and declines.

There has been a lot of focus on the period from 2006 onwards in terms of increasing commodity prices and price volatility. Table 1 shows that the period 2005–2009 does indeed exhibit high volatility levels. This phenomenon is, however, not without exceptions. The volatility of lean hogs has actually decreased compared to the previous time periods.

We see that there is great variation in SDs and kurtosis, both across commodities and time periods. Corn is a commodity with a variety of uses and a product that is heavily traded on exchanges. We see that this commodity had an upsurge in volatility levels after 2005. For the period 2005–2010 this could in part be explained by large price movements that came with the 2008 price spike and the subsequent financial crisis, but it is less obvious as to what is causing the high volatility levels after 2010. Increased demand for corn for the production of biofuel in the United States, as well as adverse weather conditions in the US Corn Belt, are possible culprits. While the risk is increasing in terms of volatility, we see no evidence of increasing tail risk. We see that the return series exhibit fat tails relative to

Table 1. Descriptive statistics

	Corn	Wheat	Soybean	Soyaoil	Sugar	Cocoa	Orange juice	Lean hogs	Feeder cattle
1995–2000									
St. Dev	0.22	0.25	0.21	0.19	0.29	0.25	0.34	0.26	0.12
Kurtosis	1.99	2.26	3.35	1.95	3.06	3.39	17.08	2.01	1.44
Skewness	−0.01	−0.24	−0.12	0.20	−0.18	0.52	1.30	−0.28	0.18
2000–2005									
St. Dev.	0.23	0.26	0.24	0.24	0.36	0.36	0.26	0.25	0.12
Kurtosis	1.35	1.62	2.29	1.20	6.53	1.45	6.28	0.92	8.25
Skewness	0.26	0.33	−0.20	0.15	−1.10	−0.18	0.32	−0.19	−0.88
2005–2010									
St. Dev.	0.34	0.37	0.30	0.29	0.34	0.32	0.35	0.22	0.13
Kurtosis	1.00	1.25	1.88	2.16	1.97	2.99	4.08	1.31	1.92
Skewness	−0.07	−0.08	−0.42	0.02	−0.20	−0.50	0.16	−0.22	−0.21
2010–2013									
St. Dev.	0.31	0.34	0.22	0.20	0.35	0.27	0.33	0.17	0.10
Kurtosis	2.33	1.99	1.58	1.18	2.71	1.10	3.37	0.90	1.33
Skewness	−0.09	0.06	−0.17	0.06	−0.50	−0.14	−0.37	−0.02	−0.13

AQ16 *Notes*: *Kurtoses are reported as excess kurtosis. SDs are annualized. The number of observations in each period is ≈ 1200, except in the last period where the number of daily observations is 991.

the normal distribution, but the amount of excess kurtosis is moderate.

Like corn, wheat prices have been characterized by increasing volatility levels after 2000 as measured by SD. We also see that wheat prices are more volatile than corn prices for all time periods. The latter phenomenon is puzzling for two reasons. First, we note that corn exports are dominated by one major player, the United States. Wheat benefits from having a number of exporters, and while the United States is still the largest, their export competes with those of Canada, Russia, Ukraine, Argentina and Australia, among others. Some argue that there should be substantial diversification benefits from producing in different regions, as production shortfall in one region can be made up by other regions. However, these data tell another story – wheat prices have been significantly more volatile relative to corn prices since the late 1990s.

The second puzzle relates specifically to the premise that speculation might drive commodity prices. The amount of corn traded on exchanges is much larger than that of wheat. If it is true that speculation is driving price volatility, one should expect relatively more volatile corn prices. A counterargument would be that the large number of trades in corn makes this market more robust against speculative influences.

Figure 2 displays the evolution of volatility and kurtosis for corn front month futures contracts from 1995 through 2013. We use rolling window estimation to illustrate how descriptive statistics sometimes fail to capture all the subtleties of a probability distribution. The problematic areas occur when volatility levels are low while kurtosis is high, like we see around the year-end of 2003 and also in the latter part of 2013. It is common to associate low volatility levels with small amounts of risk. However, several of the risk models in modern finance assume a normal distribution, which implies that these models will misjudge the probability of observing large price changes in the presence of heavy tails. When the return distribution exhibits fat tails, i.e. when kurtosis is high, the estimated SD severely understates the true degree of observations far away from the mean. It follows that thinking solely in terms of normally distributed returns will seriously underestimate risk when kurtosis levels are high.

IV. Method

Tail-related risk is today an integrated part of modern risk management. The branch of statistics that deals with probability distributions and extreme deviations from the mean are generally referred to as EVT. In this article we use a variation of the block maxima estimation method. This approach considers the maximum or minimum a variable takes in sequential periods. Formally, the limit law for the maxima M_n, where n is the size of the subsample (block), is given by the Fisher–Tippett–Gnedenko theorem (Fisher and Tippett, 1928; Gnedenko, 1943):

Let (X_n) be a sequence of i.i.d. random variables. If there exist norming constants $c_n > 0\, d_n \in \mathbb{R}$ and

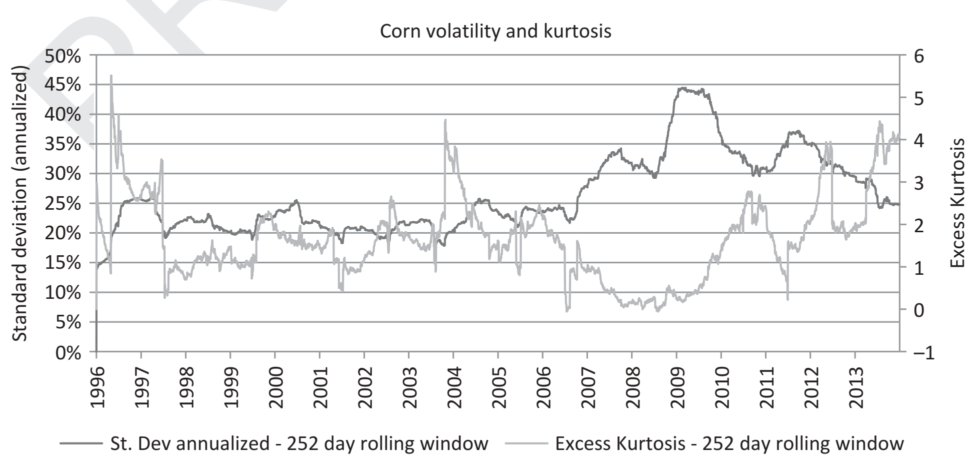

Fig. 2. Corn continuous settlement price – Uc/Bc, rolling window estimates of SD and excess kurtosis based on daily log-returns, 2 January 1995 to 31 December 2013

some nondegenerate distribution function H such that

$$c_n^{-1}(M_n - d_n) \xrightarrow{d} H \quad (1)$$

then H belongs to one of the three following distribution functions:

$$\textit{Fréchet}: \Phi_\alpha(x) = \begin{cases} 0, x \le 0 \\ \exp[-x^{-\alpha}], x > 0 \end{cases} \alpha > 0$$

$$\textit{Weibull}: \Psi_\alpha(x) = \begin{cases} \exp[-(-x)^{-\alpha}], x \le 0 \\ 1, x > 0 \end{cases} \alpha > 0$$

$$\textit{Gumbel}: \Lambda(x) = \exp[-e^{-x}], x \in \mathbb{R}$$

The theorem above is one of the fundamental results in EVT, and can be thought of as analogous to the central limit problem in standard probability theory (Embrechts *et al.*, 1997). The key insight is that the asymptotic distribution of the maximum values belongs to one of the three distributions, regardless of the original data. The existence of a sequence of norming constants is not always guaranteed, though for virtually any textbook distribution it has been proven that location and scale parameters are defined AQ3 (Embrechts *et al.*, 1997; Rocco, 2014). The generalized extreme value (GEV) distribution introduced by Jenkinson (1955) combines these three distributions into a single function with the following cumulative distribution function:

$$H(x;k,\alpha,\xi) = \begin{cases} \exp\left[-\{1 - k(x-\xi)/\alpha\}^{1/k}\right], & k \neq 0 \\ \exp[-\exp\{-(x-\xi)/\alpha\}], & k = 0 \end{cases} \quad (2)$$

where k, α and ξ are the shape, scale and location parameter, respectively. When $k > 0$, we have the Fréchet distribution family with heavy tails. For $k < 0$, we get the Weibull distribution with a short tail and finite right end-point, and for $k = 0$ the GEV distribution reduces to the Gumbel that encompasses several distributions with tails ranging from light to moderately heavy.

To assess whether the extreme risk profile of agricultural commodities has changed systematically during the period 1995–2013, we define the first and ninety-ninth percentiles as block minima and maxima, respectively. The percentiles are calculated as medians. Because the tail distributions are highly asymmetrical, the mean no longer represents a good measure of central tendency. As for the block size, we choose to divide by calendar years to avoid any seasonal effects. This gives 18 nonoverlapping subsamples containing daily log-returns of the successive calendar years.

One inherent difficulty in assessing tail-related risk is the fact that extreme events are, by definition, rare. This means that it is challenging to make statistical inference about changes in extreme risk from one period to the next. To make assessment about inference, we use the bootstrapping technique to estimate confidence intervals around the annual distributions of extremes. The bootstrap creates a large number of datasets from the original data using resampling, and then computes all statistical measures from these datasets (see Efron, 1979, for details). We produce 2000 bootstrapped distributions per year for each commodity in order to create bias-corrected confidence intervals (Poi, 2004). This correction is found to have better asymptotic properties than the normal approximation (Efron, 1987). In order to avoid inflating Type I error when comparing the actual percentiles and their respective confidence intervals over multiple years, we employ the strict Bonferroni adjustment to the 5% significance level by assuming three comparisons across the time period 1995–2013 (i.e. significance level/3 = 1.67%, yielding a confidence interval of 100% – 1.67% = 98.33%). The choice of number of comparisons is arbitrary, but informed by the fact that the Bonferroni method is overcompensating for the risk of Type I error. A visual comparison of the 2013 percentile (ninety-ninth or first) with these confidence intervals over time sheds light on whether tail-related risk is changing. This visual method is informative since the reader can choose which time periods are most interesting to compare across.

As a rudimentary robustness check, we calculate nonparametric confidence intervals for the median based on the binominal distribution. Upper and lower confidence intervals are calculated according to the following approximation, analogous to Campbell and Gardner (1988):

$$CI = nq \pm Z\sqrt{nq(1-q)}$$

where n is the sample size and q denotes which quantile we examine. In our case, $q = 1/2$, because we are interested in the median. The value of Z depends on the confidence level required, and is given by the standard normal distribution. The nonparametric confidence intervals overlap the bias-corrected ones with high proximity, and we thus refrain from reporting them in the results section of this article.

We also assess the change to the probability-weighted moments estimator for the shape parameter of the GEV distribution, $\hat{k}$, through the same subsequent periods of one year. Probability-weighted moments (PWMs) estimators compare favourably with estimators obtained by maximum likelihood as shown in Hosking *et al.* (1985). By using the method of PWM, we were able to utilize a simple yet powerful test of whether the tail belongs to the domain of a Fréchet, Weibull or Gumbel distribution. If the shape parameter $\hat{k} = 0$, the estimator is asymptotically distributed as $N(0, 0.5633/n)$. By calculating $Z = k\sqrt{(n/0.5633)}$, we could compare this statistic with the critical values of a standard normal distribution (Hosking *et al.*, 1985). Significant positive values of Z imply the rejection of the null hypothesis in favour of $\hat{k} > 0$, while significant negative values of Z imply rejection in favour of $\hat{k} < 0$. All estimates were calculated using the bootstrapping technique.

V. Results

In this section, we give an overview of our empirical findings. Figure 3 displays the evolution of the first percentile for corn futures contracts from 1995 through 2013. The straight, horizontal line represents the actual percentile value in 2013. Examining the first percentile, we see that this line for the most part falls outside the bias-corrected bootstrapped confidence intervals prior to 2006. This can be interpreted as an indication of increased extreme risk after 2006, although the evidence is not conclusive. We note that the large 'dip' to the right of the annual distribution of minima coincides with the onset of the financial crisis. Considering extreme risk to the upside in Fig. 4, we see a similar pattern with a breaking point in 2006. The annual distribution of maxima suggests that there was a relatively larger amount of tail risk in the time period 2006–2012, with large price deviations. In 2013, extreme risk reverts to the post-2006 level.

In sum, we find some indications of corn price changes being more extreme after 2006, with upside risk normalizing in 2013. A similar pattern is detected in the price series for wheat. In Fig. 5, we see that both extreme outliers, as well as the confidence intervals around them, are shifting upwards after 2002. The actual block maxima percentile value in 2013 falls below the bootstrapped confidence interval on all but three occasions during the time period we examine. If we consider the fundamentals, we find that a large part of the build-up in

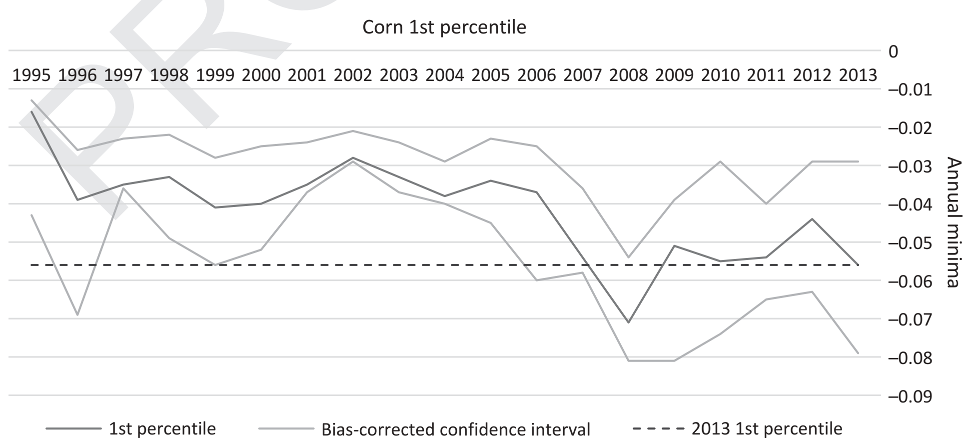

Fig. 3. Corn continuous settlement price – Uc/Bc, first percentile with bootstrap confidence intervals, 1995–2013. The horizontal dashed line represents the actual percentile value in 2013

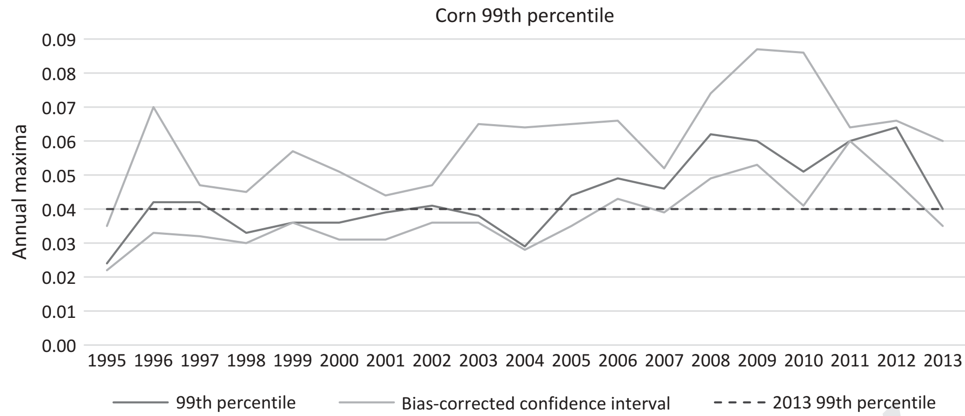

Fig. 4. Corn continuous settlement price – Uc/Bc, second percentile with bootstrap confidence intervals, 1995–2013. The horizontal dashed line represents the actual percentile value in 2013

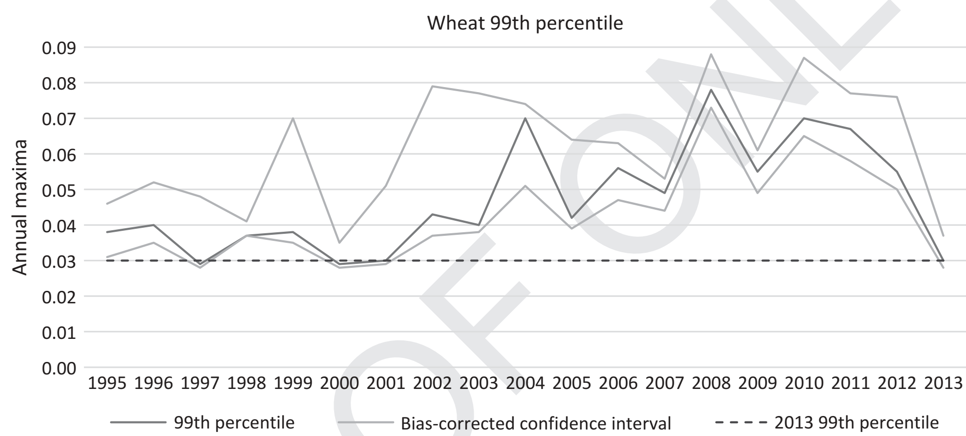

Fig. 5. Wheat continuous settlement price – Uc/Bw, ninety-ninth percentile with bootstrap confidence intervals, 1995–2013. The horizontal dashed line represents the actual percentile value in 2013

wheat prices prior to the year 2006–2007 can be explained by unfavourable weather conditions; most notably the drought conditions in Ukraine had a severe impact on wheat prices in this period. Ukraine also experienced drought and a large reduction in yields in 2012, which coincided with unfavourable weather conditions in the US Corn Belt. In other words, adverse weather conditions are a likely culprit for increasing prices and price variability.

The results for corn and wheat are somewhat atypical across the return series we have investigated. We did not find any evidence of increasing tail risk in the return series for the other commodities. Figure 6 depicts the tail risk profile of soybean futures contracts, and as before the straight line crossing the diagram horizontally represents the actual ninety-ninth percentile value in 2013. We see that this value mainly falls inside the estimated confidence interval for the entire time period, and there is no upward trend in the distribution of annual extremes. Hence, there is nothing here that suggests that extreme risk to the upside has increased since the late 1990s for this commodity. Further, the width of the confidence band is fairly uniform for the period.

That we only find evidence of increasing extreme risk in the tail distributions for corn and wheat suggests that the aforementioned weather events, and/or new and persistent demand for corn as an input in biofuel production, could be driving the increase in tail-related risk after 2006. Taken together with the analysis done by Gilbert and Morgan (2010) where the hypothesis of increased food price volatility is

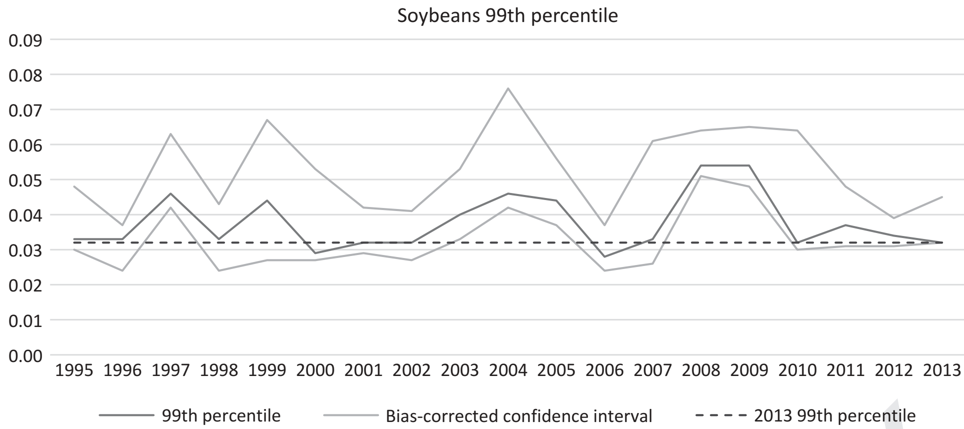

Fig. 6. Soybeans continuous settlement price – Uc/Bs, ninety-ninth percentile with bootstrap confidence intervals, 1995–2013. The horizontal dashed line represents the actual percentile value in 2013

contested, this raises doubts regarding the claim that index tracking and speculation uniformly have generated increased and excessive price volatility.

An analysis of the estimated shape-parameters of the GEV-distribution further supports the hypothesis that there is no systematic change in the extreme risk associated with commodity investments. Block sizes of one year should be of sufficient size for the asymptotic properties of the Fisher–Tippett–Gnedenko theorem to hold, and also provide enough information to get robust estimates of the distribution parameters.

Table 2 summarizes the parameter estimates for the right tail of the distributions of the return series. We see that most of the tails belong in the Fréchet

Table 2. Estimated k-parameters – right tail

	Corn	Wheat	Soybean	Soyaoil	Sugar	Cocoa	Orange juice	Lean hogs	Feeder cattle
Year									
1995	−0.01	**0.39**	**0.30**	**1.09**	**0.65**	**0.76**	**0.58**	**0.64**	**−0.15**
1996	**−0.08**	**0.05**	**0.63**	**0.23**	**0.99**	**−0.41**	**0.97**	**1.06**	**0.74**
1997	**0.78**	**−0.20**	**0.05**	**0.30**	**1.22**	0.03	**0.05**	**1.05**	**0.38**
1998	0.02	**0.59**	**0.23**	**1.01**	**1.23**	**0.20**	**−0.16**	**1.63**	**1.21**
1999	**−0.13**	**−0.16**	**0.09**	**0.22**	**0.40**	**0.45**	**−0.62**	**0.31**	**0.30**
2000	**0.10**	0.00	**−0.41**	**−0.14**	**0.60**	−0.03	**−0.22**	**−0.16**	**0.58**
2001	**0.74**	**−0.46**	**0.32**	**−0.34**	**0.33**	**0.05**	**0.45**	**0.35**	**1.12**
2002	**0.53**	**−0.30**	**0.14**	**0.12**	**0.52**	**−0.25**	**0.21**	**0.80**	**2.65**
2003	**−0.08**	**−0.42**	**0.15**	**0.26**	**−0.41**	**0.41**	**0.43**	**0.42**	**0.30**
2004	**−0.21**	**0.78**	**−0.21**	**0.25**	**−0.11**	**0.04**	**−0.26**	**−0.09**	**0.59**
2005	**0.07**	**−0.17**	**0.26**	**0.02**	0.05	**0.23**	**−0.09**	**−0.19**	**0.25**
2006	**0.05**	**0.64**	**0.06**	**−0.47**	**0.36**	**0.22**	**−0.47**	**−0.36**	**0.13**
2007	**0.60**	**0.35**	**−0.11**	**−0.14**	−0.01	**0.49**	**0.96**	**0.12**	**0.11**
2008	**0.42**	**0.29**	**0.16**	**0.39**	**0.42**	**−0.13**	**−0.12**	**0.47**	**0.08**
2009	**−0.06**	**0.27**	**0.47**	**0.28**	**0.35**	**−0.17**	**−0.20**	**0.63**	**0.08**
2010	**−0.13**	**0.35**	**−0.38**	**−0.08**	**0.80**	**0.34**	**0.27**	**0.38**	**0.10**
2011	**0.99**	**0.57**	**0.22**	**−0.06**	**0.05**	**−0.23**	**0.34**	**0.68**	**0.72**
2012	**0.81**	**0.13**	**0.40**	**0.52**	**0.49**	**0.49**	**−0.12**	**0.79**	**0.08**
2013	**0.13**	**0.21**	0.00	**0.10**	**0.74**	**0.48**	−0.02	**0.16**	**0.52**

Notes: This panel presents bootstrap-estimated k-parameters for 10 different commodities. Figures marked in bold indicate that these estimates are significantly different from zero at a 5% level, based on a test on the PWM estimator of k. Under the null of $\hat{k} = 0$, the estimator is asymptotically distributed as $N(0, 0.5633)/n)$, and the test is performed by comparing the statistic $Z = k\sqrt{(n/0.5633)}$ with the critical values of a standard normal distribution (Hosking *et al.*, 1985). Significant positive values of Z imply rejection of H_0 in favour of $k > 0$, and significant negative values of Z imply rejection in favour of $k < 0$.

domain, while a few follow the Weibull or Gumbel distributions. Since the latter two comprise of lighter-tail distributions (to be specific, the Gumbel domain features a variety of tail distribution functions ranging from light to moderately heavy), we confine our discussion to the Fréchet domain of attraction. The first observation we make is that all but 10 of these parameters are confined within the interval [0,1]. In fact, only 42 out of the 162 estimated parameters are above 0.5. There is no form of clustering among these values, and we see no systematic increase in tail fatness that coincides with increasing commodity prices. On an individual commodity level, we see that the shape-parameters for sugar, lean hogs and feeder cattle indicate a large number of dramatic price changes. However, we find no commodity that shows systematically increasing tail indexes, which suggests that extreme risk to the upside has not increased during the time period we examine.

Examining the left side of the distributions in Table 3, we see that the risk of large deviations to the downside is much greater than the risk of dramatic price increases. The estimated parameters suggest that the majority of the left tails of commodity return distributions belong to the Fréchet domain. The bulk of the parameters are estimated to be in the area of 0.5, and many are as high as 1 indicating very heavy tails. But this result merely confirms a well-known fact about commodity returns, namely that their distributions are fat-tailed relative to the normal distribution. It seems not to be any discernible pattern of increasing commodity market risk in the left tail of the distribution, regardless of which individual commodity we are looking at. While certain commodity returns such as lean hogs display distributions with heavy left tails, this characteristic is uniform across the entire time period we analyse.

VI. Concluding Remarks

Our analysis confirms a well-established fact, namely that the distribution of commodity price returns is fat-tailed relative to the Gaussian. Beyond this, examining annual distributions of extremes with their

Table 3. Estimated k-parameters – left tail

	Corn	Wheat	Soybean	Soyaoil	Sugar	Cocoa	Orange juice	Lean hogs	Feeder cattle
Year									
1995	**0.99**	**0.61**	**0.17**	**0.11**	**0.20**	**0.93**	**0.46**	**0.08**	**−0.10**
1996	**0.76**	**0.13**	**−0.06**	**0.90**	**0.71**	**0.42**	**0.32**	**0.10**	**−0.34**
1997	**−0.35**	**0.39**	**0.70**	**0.78**	0.03	**0.36**	**0.47**	**−0.15**	**−0.47**
1998	**0.65**	**1.02**	**0.83**	**0.96**	**−0.13**	**0.58**	**0.72**	**−0.07**	**−0.40**
1999	**0.60**	**0.26**	**0.83**	**0.49**	**0.53**	**−0.07**	**0.41**	**0.99**	**0.52**
2000	**0.23**	**0.83**	**0.17**	**0.93**	**0.79**	**1.08**	**−0.04**	**0.47**	**0.47**
2001	**−0.08**	**0.06**	**0.39**	**0.07**	**0.74**	**0.60**	**0.64**	**−0.14**	**1.12**
2002	**1.40**	**0.40**	**−0.43**	**0.31**	**0.93**	**0.81**	**0.24**	**0.26**	0.00
2003	0.00	**0.65**	**0.18**	**0.62**	**0.24**	**0.33**	**0.83**	**0.34**	**0.49**
2004	**0.06**	**0.44**	**0.52**	**0.32**	**0.34**	0.02	**−0.33**	**0.23**	**−0.13**
2005	**0.92**	**0.30**	**0.63**	**0.44**	**−0.23**	**0.96**	**0.54**	**0.65**	**0.51**
2006	**0.60**	**0.47**	**−0.11**	**−0.12**	**0.32**	**1.45**	**0.42**	**−0.10**	**0.24**
2007	**−0.07**	**0.22**	**−0.15**	**0.79**	**0.28**	**0.31**	**0.16**	**0.19**	**0.53**
2008	**0.16**	−0.01	**−0.16**	**0.20**	**0.73**	**0.62**	**0.74**	**0.17**	**−0.27**
2009	**0.70**	**0.96**	0.02	**0.70**	**0.18**	**0.69**	**0.29**	**0.28**	**−0.17**
2010	**0.18**	**0.12**	**0.24**	**0.33**	**0.26**	**0.18**	**1.52**	**−0.15**	**0.67**
2011	**1.05**	**−0.01**	**0.29**	**0.51**	**0.31**	**0.76**	**0.11**	**0.11**	**0.34**
2012	**0.62**	**0.13**	**0.55**	**0.51**	**0.28**	**0.31**	**0.44**	**0.19**	**−0.48**
2013	**0.38**	**1.62**	**0.60**	**0.20**	0.02	**0.33**	**0.11**	**1.05**	**0.50**

Notes: This panel presents bootstrap-estimated k-parameters for 10 different commodities. Figures marked in bold indicate that these estimates are significantly different from zero at a 5% level, based on a test on the PWM estimator of k. Under the null of $\hat{k} = 0$, the estimator is asymptotically distributed as $N(0, 0.5633)/n)$, and the test is performed by comparing the statistic $Z = k\sqrt{(n/0.5633)}$ with the critical values of a standard normal distribution (Hosking *et al.*, 1985). Significant positive values of Z imply rejection of H_0 in favour of $k > 0$, and significant negative values of Z imply rejection in favour of $k < 0$.

bootstrapped confidence intervals gives no evidence of increasing tail-related risk, with a possible exception for corn and wheat. An analysis of estimated shape-parameters of the GEV-distribution further substantiates that there is no systematic change in the extreme risk associated with commodity investments. We find that the return distributions of a majority of the commodities we have examined belong in the Frechét domain of attraction. This suggests commodity return distributions with heavy tails throughout the period 1995–2013.

Our findings do not support the hypothesis of increasingly extreme commodity market risk. This is in line with the results obtained by Gilbert and Morgan (2010), who use their conclusion to highlight that volatility has been high in the past before reverting to normal levels. The results in our analysis further cast doubt on the claim that the substantial growth in index tracking and speculation during the last 10 years has generated increased (and excessive) price volatility. Our results support the traditional view that agricultural price volatility is mainly driven by demand- and supply-side shocks, typically caused by adverse weather or dramatic political decisions and events. This is an important finding, because volatility driven by fundamentals cannot be tamed by regulation. To the contrary, one needs to look for good ways to manage this risk.

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Disclosure statement

No potential conflict of interest was reported by the authors. AQ4

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Appendix

Commodity	Contract specifications	Mnemonic
Corn	CBOT Contracts of 5000 bushels	CW.CS04
Wheat	CBOT Contracts of 5000 bushels	CW.CS04
Soybeans	CBOT Contracts of 5000 bushels	CS.CS04
Soyaoil	CBOT Contracts of 60 000 pounds	CBOCS04
Lean Hogs	CME Contracts of 40 000 pounds	CLHCS04
Sugar	CSCE No 11, Contracts of 112 000 pounds	NSBCS04
Feeder cattle	CME Contracts of 50 000 pounds	CFDCS04
Cocoa	CSCE Contracts of 10 metric tons	NCCCS04
Orange juice	NYCE Contracts of 15 000 pounds, frozen concentrated	NJOCS04

AQ15 *Note*: CBOT, Chicago Board of Trade; CME, Chicago Mercantile Exchange; NYCE, New York Commodity Exchange.