Received: 18 January 2019 | Revised: 18 January 2019

DOI: 10.1002/fut.21999

RESEARCH ARTICLE

WILEY THE JOURNAL OF FUTURES MARKETS

On commodity price limits

Rajkumar Janardanan[1] | **Xiao Qiao**[2] | **K. Geert Rouwenhorst**[3]

[1]SummerHaven Investment Management, LLC, Stamford, Connecticut

[2]Paraconic Technologies US Inc, New York, New York

[3]Yale School of Management, Yale University, New Haven, Connecticut

Correspondence
Rajkumar Janardanan, SummerHaven Investment Management, LLC, Stamford, CT 06902.
Email: rjanardanan@summerhavenim.com

Funding information
J. P Morgan Center for Commodities at the University of Colorado Denver

Abstract

This paper examines the behavior of futures prices and trader positions around the occurrence of price limits in commodity futures markets. We ask whether limit events are the result of shocks to fundamental volatility or the result of temporary volatility induced by the trading of noncommercial market participants (speculators). We find little evidence that limits events are the result of speculative activity, but instead associated with shocks to fundamentals that lead to persistent price changes. When futures trading halts price discovery migrates to options markets, but option prices provide a biased estimate of subsequent future prices when trading resumes.

KEYWORDS

circuit breakers, commodity futures, commodity options, price limits, speculation, speculative trading

JEL CLASSIFICATION

G13, G14

1 | INTRODUCTION

Exchanges use a variety of mechanisms to curb volatility, such as circuit breakers, price controls, and price limits. In particular, commodity futures markets primarily use price limits which restrict prices from rising above or falling below prespecified levels. Limits can impact market microstructure, as well as affect real outcomes by restricting trading when incentives and benefits to reallocating resources are potentially large.

Price limits in commodity markets have a long history that goes back to the first commodity futures exchange in the 18th century: The Dojima rice exchange in Japan curbed the price movements of rice futures during a time when prices were falling (Moser, 1990; Schaede, 1989). The stated purpose was to avoid excess volatility. Price limits were first introduced in the United States during World War I when the New York Cotton Exchange restricted the daily price change of cotton futures to three cents per pound on August 27, 1917 (Howell, 1934).[1] The Cotton Exchange's justification for imposing limits was "to avoid abnormal fluctuations of price created by the European war, and injurious speculation incident thereto"[2]—a sentiment that was shared by news reports which referred to "abundant evidence of hoarding and speculation" but "no real scarcity of raw materials."[3] In 1922, the US Supreme Court ruled to support price limits:

"It was shown that a continually fluctuating, and not a stable, market is the desire of speculators. Such a market is against the interests of the producer; he must have stable prices in order to market his crop to best advantage. A market without wide and frequent price fluctuations would greatly benefit the producer."[4]

[1]Soon after in December, limits were imposed in Hog markets. Grain markets had absolute price limits rather than limits on price changes.

[2]Cotton Fluctuations Limited, *Wall Street Journal*, August 16, 1917.

[3]The *New York Times* of August 19, 1917 notes: "There is no real scarcity of the raw materials, but there is abundant evidence of hoarding or manipulation. Take the case of cotton, for instance."

[4]Senate Report No. 212, 67th Congress.

This brief history of price limits illustrates the view that limits are a tool to reduce volatility caused by speculation. In this view, volatility is perceived to have a large transitory component caused by uninformed traders or speculators who push prices away from fundamentals. Slowing down price changes provides informed traders an opportunity to enter the market and steer prices towards fundamental values. Speculative activity is expected to decrease around limits: Speculators reduce their long positions after limit ups and reduce their short positions after limit downs, thereby stop pushing prices away to more extreme levels. Price changes are likely to reverse and volatility is likely to decline following limit events (Ma, Rao, & Sears, 1989).

An alternative view is that futures price volatility mostly reflects news about fundamentals, which are persistent over time. Having price limits in place merely postpones inevitable price changes and slows down price discovery. Because limits dampen fundamental volatility rather than speculative volatility, they are not effective at restricting speculation. In fact, price limits may even negatively alter the trading behavior of market participants, encouraging them to speed up trading to avoid being closed out just before price limits occur (Kyle, 1988; Lehmann, 1989). Along this line of reasoning, speculators should not change their trading behavior on limit days compared to nonlimit days. Following limit events, prices are likely to continue in the same direction and volatility should not decrease.

The above views are not necessarily mutually exclusive: It is likely that volatility has both temporary and permanent components. The net impact of limits on market participants, as well as the behavior of prices and positions, is an empirical question. It is against this background that our paper attempts to answer three questions, using a large sample of more than 5,000 limit events in 12 commodity futures markets over a 25-year period.

The first question we address is whether price limits mitigate speculative activity of market participants. Using positions data from the Commodity Futures Trading Commission (CFTC), we find direct evidence against reduced speculation after price limits. Noncommercial traders, who are an important source of speculative capital, do not change their long positions following limit up events. Instead, they significantly reduce their short positions. This behavior, rather than decreasing, increases their *net* long positions following limit up events. Similarly, following limit down events, noncommercials do not change their short positions and reduce their long positions, resulting in an increase of net short positions. Our finding is robust to different regression specifications controlling for determinants of noncommercial position changes.

The second question we ask is what causes limit events to occur? Price limits are more likely to occur when futures price volatility is elevated. High volatility could be symptomatic of increased speculative activity or could reflect changing fundamentals. We provide evidence that the elevated volatility does not appear to be associated with higher speculation, as the behavior of noncommercial traders does not appear to lead to limits: Long and short positions of noncommercial traders do not materially change before limit events. Instead, high price volatility appears to be related to low levels of physical commodity inventories. Just before limit events, the front end of the futures curve is often in steep backwardation. For storable commodities, a steeply backwardated futures curve reflects low inventories, which lead to increased stock-out risk (Deaton & Laroque, 1992). Higher stock-out risk is associated with high futures volatility, which in turn raises the probability that price limits are hit. Our results suggest that the conditions leading up to limit events are fundamental in nature rather than speculative.

If limit events occur due to a shift in commodity fundamentals, any related price effects will likely persist. We investigate price behavior around limits and find large and persistent price continuations across almost all commodities we examine. We treat limit days as "events" and trace out average returns after these events and find large price continuations do not reverse even after 2 weeks. Previous studies placed emphasis on the day immediately after limit events (Evans & Mahoney, 1996, 1997; Hall, Kofman, & Manaster, 2006; Reiffen & Buyuksahin, 2010; Reiffen, Buyuksahin, & Haigh, 2006). However, speculation could subside in the days following limit events, but not necessarily on the day after. Tracking returns over longer horizons allows us to separate persistent price effects from return reversal after several days.

Since price limits occur for fundamental reasons and do not stop speculation, do they affect price discovery in futures markets? This is our third question. If market participants can easily switch between commodity futures and other financial instruments, we may expect price discovery to migrate to other related markets. Options markets are closely connected to the futures markets but currently do not have price limits. Historically, price limits on options had been significantly looser than limits on futures and were almost never hit. Therefore, options provide an ideal laboratory to understand price discovery around limit events and to gauge what unrestricted futures prices would be if price limits did not exist. We explore this idea and compare option-implied futures prices at the time of limit events to subsequent prices when trading reopens in the underlying futures markets. We find that these option-implied futures prices are biased but informative predictors of subsequent futures prices. In forecasting regressions, a 1% increase in the return calculated from the limit-day closing price to the option-implied price is associated with a 0.80% increase in the close-to-open futures returns. The migration of price discovery to options markets is also reflected in the open interest data reported by the CFTC: The ratio of open interest of combined futures and options positions to open interest of futures-only positions increases after limits events. Taken together, the evidence suggests that price discovery moves from the futures to the options markets after limit events.

The empirical literature on price limits in commodity futures markets is relatively small, and there are few recent studies. Compared to the literature, our sample is substantially more comprehensive covering more markets over a longer time period. Ma et al. (1989) analyze price movements and volatility for silver, corn, soybeans, and Treasury bond markets, and report opposite conclusions (price reversals) to our paper. Evans and Mahoney (1996) study the migration of trading volume from futures to options markets around limit events in the cotton futures market during 20 trading days in September 1995. Hall et al. (2006) study volume migration in the coffee market around limit days. Reiffen et al. (2006) also document 1-day price continuation around limit days, although for a much smaller set of commodity futures and over a shorter time period. We differ from Reiffen et al. (2006) in that our focus is on exploring the fundamental reasons why limits occur and the important question of whether the behavior of market participants changes as a consequence of touching limits. To answer these questions, we analyze trader positions, fundamental market information, and the persistence of shocks to prices beyond single-day price continuations.

2 | BACKGROUND ON LIMITS AND DATA

2.1 | An example of price limits

Suppose the price limit on lean hogs is $3.00 per hundred weight (cwt). If yesterday's closing price is $30, then today's trades must range between $27 and $33. Otherwise, the futures market on lean hogs will stop trading until the price trades within the range. If trading does not resume during trading hours, the market will close at the limit and experience a "limit day."

After a limit day, limits are often expanded. For example, following a limit move in lean hogs, the limit expands 50% from $3 to $4.5. The limit remains unchanged at $4.5 for any following consecutive limit days. Expandable limits are common, and all commodities we consider share this feature.[5]

Price limits are distinct from circuit breakers. Circuit breakers halt trading for a fixed time, whereas trading is still permitted between the upper and lower bounds for price limits. Price limits also differ from price controls, which restrict the level of prices rather than the change.

2.2 | Data

Price limits are mostly for agricultural and livestock commodities; they are uncommon in energy and metals markets. We consider 12 commodities: soybean oil (BO), corn (C), cotton (CT), feeder cattle (FC), Kansas City wheat (KW), live cattle (LC), lean hogs (LH), oats (O), rough rice (RR), soybean (S), soybean meal (SM), and soft red winter wheat (W). Daily opening and closing futures prices are from Bloomberg. Our sample is from January 07, 1991 to May 23, 2016.

Information on price limits is from the CME Group. We identify limit days by comparing daily close-to-close price changes with the exchange price limits, accounting for expandable limits and any changes in regulation over time. If the price change equals the price limit, we mark that day as either a "limit up" or a "limit down" day. Cotton price limits data were collected by Judith Ganes, a renowned consultant on softs markets.[6]

Options data are from Commodity Research Bureau (CRB). For each futures contract, we select the closest at-the-money (ATM) put and call relative to the limit-day futures closing price. We use the Citigroup 3-month Treasury Bill Index from Bloomberg to construct the risk-free rate. Implied volatility calculated using the options pricing model of Black (1976) are also collected from CRB.

Options data are relatively sparse before 2005. In addition, options often do not trade for long-date futures contracts, in which case we are unable to find matching options prices when long-date futures hit a limit. For these

[5] Expandable limits have not always existed. Before May 22, 2006, Lean Hogs limits were fixed at $3.

[6] http://www.jganesconsulting.com.

TABLE 1 Price limits summary statistics, January 07, 1991–May 23, 2016

	BO	C	CT	FC	KW	LC	LH	O	RR	S	SM	W	Total
Number of limits	340	364	877	1,036	191	535	515	262	692	302	266	221	5,601
Limit up	146	165	480	414	122	236	259	113	322	107	112	144	2,620
Limit down	194	199	397	622	69	299	256	149	370	195	154	77	2,981
2 consecutive limits	29	13	142	125	39	53	46	15	61	13	4	31	571
2 cons limit ups	2	5	96	30	29	27	18	5	26	4	3	24	269
2 cons limit downs	27	8	46	95	10	26	28	10	35	9	1	7	302
3 consecutive limits	1	2	45	40	10	13	9	2	12	0	0	5	139
3 cons limit ups	0	1	37	2	10	6	3	1	4	0	0	5	69
3 cons limit downs	1	1	8	38	0	7	6	1	8	0	0	0	70
4 consecutive limits	0	0	20	17	4	7	2	0	3	0	0	3	56
4 cons limit ups	0	0	16	0	4	4	0	0	0	0	0	3	27
4 cons limit downs	0	0	4	17	0	3	2	0	3	0	0	0	29
5 consecutive limits	0	0	12	8	2	4	0	0	0	0	0	1	27
5 cons limit ups	0	0	10	0	2	3	0	0	0	0	0	1	16
5 cons limit downs	0	0	2	8	0	1	0	0	0	0	0	0	11
6 consecutive limits	0	0	5	0	0	2	0	0	0	0	0	0	7
6 cons limit ups	0	0	5	0	0	2	0	0	0	0	0	0	7
6 cons limit downs	0	0	0	0	0	0	0	0	0	0	0	0	0

Note. The summary statistics for the number of limit events for soybean oil (BO), corn (C), cotton (CT), feeder cattle (FC), Kansas City wheat (KW), live cattle (LC), lean hogs (LH), oats (O), rough rice (RR), soybean (S), soybean meal (SM), and soft red winter wheat (W) are presented. Different contracts for the same commodity are counted separately.

reasons, our options sample size is approximately 40% of the total number of limit events. CRB implied volatility, calculated using the two nearest-the-money calls and two nearest-the-money puts, is available for almost all limit events.

We use the Commitment of Traders (COT) reports published weekly by the CFTC to impute trading behavior. The report includes the long, short, and spread positions of commodity futures and options market participants, who are categorized as commercials, noncommercials, or nonreportables. We use the Disaggregated COT (DCOT), also from the CFTC, to confirm our findings.

2.3 | Summary statistics

On each day, we look across the futures curve for each commodity and determine how many contracts hit price limits. We count each contract hitting a limit as a separate event. For example, if the July and August contracts of corn are both limit up, we would count them as two limit up events.

Table 1 presents the summary statistics for limit events. In our sample, there is a total of 2,620 limit up and 2,981 limit down events. About 10% of these are consecutive events: two limit ups or downs in a row. Specifically, there were 269 consecutive limit ups and 302 limit downs. Four or more consecutive limits occur about 1% of the time.

Live cattle experienced a notable string of limit events: The October 2003 contract hit limit up for seven consecutive days from October 06, 2003 to October 14, 2003. When Mad Cow disease was discovered in Canada in the summer of 2003, several countries imposed a ban on Canadian beef. As a consequence, US exports rose by 39% in October 2003. This event, combined with high seasonal holiday demand, pushed up spot market prices from 160 to 190 cents per pound and likely contributed to the consecutive limit up days in October 2003.[7] Cotton futures had several consecutive limit up days in April and May 1995 when there was a large open interest but only limited cotton deliverable against the New York exchanges. The circumstances forced short covering and led to a sequence of large price increases.

[7]During the Mad Cow disease episode in 2003, there were two days when different live cattle hit limit up and limit down on the same day. On October 9, the October 2003 contract hit limit up while the April, June, August, and October 2004 contracts closed limit down. A similar episode repeated on October 14 when the February contract closed limit up, but April, June, and August closed limit down. When the news of the disease reached the market, futures participants initially increased positions across all maturities. As participants gathered more information, they recognized that the price spike was likely going to be a short-term event. Over time, both export and domestic demand would adjust to new prices. As a result, although the near-term contract hit limit up, the further out contracts were sold off and hit limit down.

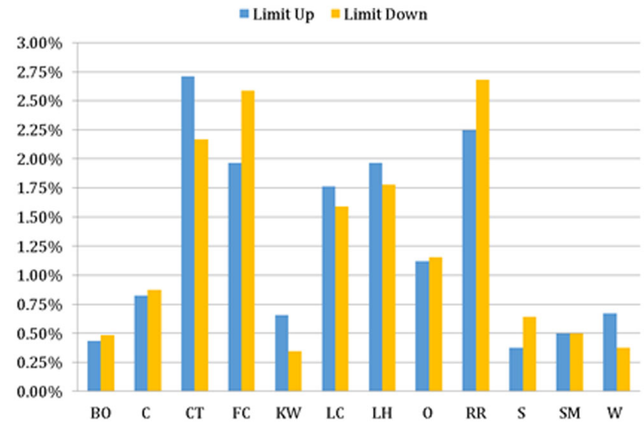

FIGURE 1 Frequency of limit occurrence. The number of limit days as a fraction of trading days is depicted. For each commodity, we count the total number of days in which at least one contract hit limit, and divide by the total number of trading days. Our sample is from January 07, 1991 to May 23, 2016 [Color figure can be viewed at wileyonlinelibrary.com]

Limit occurrences as a fraction of total trading days are shown in Figure 1. We count the total number of days with limit events, independent of how many contracts hit the limit on those days, and divide by the number of trading days in our sample. Six of the 12 commodities have limits between 0.25% and 1% of the trading days. The remaining six commodities have limits on more than 1% of the trading days. While the sample covers many limit events (5,600 across 6,600 trading days), the incidence of a commodity hitting a limit on a given day is relatively low because multiple contracts for the same commodity can hit limit on the same day. A 2% frequency of price limits in the feeder cattle market translates into 1 limit day for every 2–3 months. While this is perhaps infrequent in an absolute sense, it is important to remember that on the days when trading is halted, the desire and incentive to trade can be potentially large. This is especially true if the limit price deviates from the fundamental price.

Figure 2 illustrates that when a commodity experiences a limit day, it may affect multiple contracts. The most common limit day occurs when only one contract hits a limit: 41% of limit up days and 35% of limit down days involve only one contract. These limit events are likely caused by idiosyncratic shocks that only impact contracts at certain maturities while leaving others largely unaffected. Multiple contracts of the same commodity can hit limits on the same day. More than 5% of the limit days are for five contracts hitting the limits on the same day, and a small but nontrivial number of limit days involve six, seven, or eight contracts. Sometimes even 9 or 10 nearest contracts can hit limits on the same day. Multiple contracts hitting limits on the same day may indicate a systematic move in the underlying commodity which is not isolated to a specific maturity.

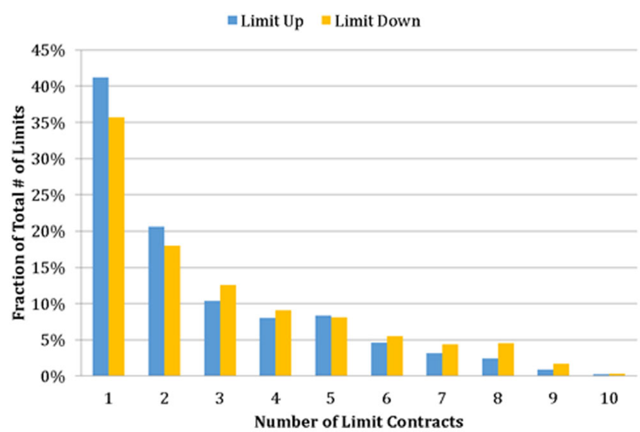

FIGURE 2 Multiple limits along the curve. It shows the number of contracts along the curve that hit price limits, considering the 10 nearest-to-maturity contracts. We tabulate these counts as a fraction of the total number of limit days. For example, on 35% of limit down days, only one contract along the curve hit limit, and on 2% of limit down days, nine contracts hit limits simultaneously. Our sample is from January 07, 1991 to May 23, 2016 [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Changes in noncommercial positions around limit days

	BO	C	CT	FC	KW	LC	LH	O	RR	S	SM	W	ALL
	Δ Noncommercial long positions around limits												
Average (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Limit up	1.0%	0.0%	0.0%	–0.4%	0.3%	**–0.7%**	0.1%	**0.7%**	–0.1%	0.4%	0.6%	0.0%	0.0%
	(1.7)	(–0.1)	(0.2)	(–1.6)	(0.8)	(–2.5)	(0.1)	(2.2)	(–0.4)	(1.5)	(1.5)	(0.0)	(–0.2)
N	146	165	480	414	122	236	259	113	322	107	112	144	2,620
Limit down	**–1.6%**	**–0.9%**	**–0.9%**	**–1.3%**	**–0.5%**	**–0.8%**	**–1.1%**	0.2%	0.0%	**–1.2%**	**–1.8%**	**–1.2%**	**–0.9%**
	(–9.0)	(–5.0)	(–5.5)	(–7.2)	(–2.5)	(–4.3)	(–3.9)	(0.5)	(0.1)	(–7.2)	(–5.6)	(–4.0)	(–12.2)
N	194	199	397	622	69	299	256	149	370	195	154	77	2,981
	Δ Noncommercial short positions around limits												
Average (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Limit up	**–2.0%**	–0.4%	**–0.9%**	**–0.4%**	–0.3%	–0.2%	**–1.3%**	0.6%	0.3%	**–0.7%**	–0.6%	**–0.7%**	**–0.5%**
	(–2.7)	(–1.9)	(–4.2)	(–2.4)	(–1.3)	(–1.0)	(–4.9)	(1.5)	(1.4)	(–3.5)	(–1.9)	(–2.9)	(–6.3)
N	146	165	480	414	122	236	259	113	322	107	112	144	2,620
Limit down	0.1%	**0.2%**	0.1%	–0.3%	–0.2%	**–0.2%**	0.4%	0.3%	0.2%	0.2%	**0.4%**	0.0%	0.1%
	(0.7)	(3.1)	(1.1)	(–1.5)	(–0.9)	(–2.3)	(1.5)	(0.8)	(1.1)	(1.7)	(2.2)	(–0.1)	(0.9)
N	194	199	397	622	69	299	256	149	370	195	154	77	2,981

Note. BO: soybean oil; C: corn; CFTC: Commodity Futures Trading Commission; COT: Commitment of Traders; CT: cotton; FC: feeder cattle; KW: Kansas City wheat; LC: live cattle; LH: lean hogs; O: oats; RR: rough rice; S: soybean; SM: soybean meal; W: soft red winter wheat.
The change in the positions of noncommercial market participants around limit days is reported. Long and short positions of noncommercials from the CFTC COT report are scaled by the open interest. "Average" reports the unconditional average in the scaled positions from week to week "Limit up" and "limit down" report the change in scaled positions around limit up and limit down events. We test for the equality of average positions and positions after limit events, and report White (1980) t-statistics in parentheses. Significance at the 5% level is shown in bold. The sample is from January 07, 1991 to May 23, 2016.

3 | SPECULATIVE TRADING AROUND LIMIT EVENTS

Do limits influence the trading decisions of market participants? To answer this question, we use the COT reports from the CFTC to uncover the trading behavior of market participants around limit days. The weekly CFTC report categorizes commodity futures and options markets participants into three groups: commercials, noncommercials, and nonreportables. Following the literature (e.g., Bessembinder, 1992; De Roon, Nijman, & Veld, 2000; Moskowitz, Ooi, & Pedersen, 2012), we take noncommercials to be important providers of speculative capital.[8] We study the trading behavior by noncommercials as a proxy for changes in speculative positions.

The CFTC reports are released after the market close on Fridays and report positions data measured as of the preceding Tuesday. We map our sample of limit events onto these Tuesday measurement intervals and calculate a weekly change in positions around each limit occurrence. The averages are reported in Table 2.

Noncommercial long and short positions on average do not change from 1 week to the next: The unconditional average change is zero. After limit up events, noncommercials do not significantly adjust their long positions in any of the 12 commodities, and the average change in scaled long positions across all commodities is zero. In contrast, traders significantly reduce their short positions for 6 out of 12 commodity markets following a limit up event. The results look similar for limit down events. Noncommercials do not change their short positions after a limit down event, but significantly reduce their long positions in 10 of the 12 commodities.

In both limit up and limit down events, therefore, noncommercials increase their *net* positions in the direction of the limit move, in effect increasing speculative pressure around limit events. These findings stand in contrast with the view that limit events reduce speculative pressure: There is no reduction in the noncommercial long positions following a limit up event and an increase instead of a decrease in the net long position. The finding that limit up events affect the positions of shorts, and limit down events influence long positions can be explained by the losses that these traders incur around large price changes. It is likely that these positions face margin calls around limit moves and force some traders to exit their positions. To highlight this channel, we study position changes around

[8]Several studies have pointed out that the CFTC classifications are noisy and potentially misclassify certain traders (Cheng, Kirilenko, & Xiong, 2014; Ederington & Lee, 2002). We repeat our analysis using the DCOT report over the period it is available, and find the same results using "Managed Money" as for noncommercials.

days of large price moves, between 90% and 100% of the limit size, where no limit was reached (Kim & Rhee, 1997). Our findings closely resemble limit days: No significant adjustment in the long positions around days of large upticks or decreases in shorts following price declines. Instead we find significant reductions to positions that experience losses. Based on these findings, we conclude that the adjustment of positions around limit events is primarily driven by traders closing positions that have incurred losses following large price moves. In this sense, there is nothing special about prices hitting a limit.

Noncommercial positions are not solely determined by price limits. Factors such as past position changes or past returns may influence speculator trading and confound the effect of limits. We examine how price limits may affect speculator positions in the presence of other factors with the following regression:

$$\Delta NC \text{ Position}_{i,m,t+} = \gamma + \beta^{\text{limit}} I^{\text{limit}}_{i,m,t} + \text{Controls} + FE_t + FE_m + \varepsilon_{i,\,m,\,t+}, \tag{1}$$

where $\Delta NC \text{ Position}_{i,m,t+} = \Delta NCL_{i,m,t+}, \Delta NCS_{i,m,t+}$ is the change in noncommercial long or short position after a price limit at time t, for commodity m, and contract i. The CFTC does not separately report positions by contract, so $\Delta NC \text{ Position}_{i,m,t+} = \Delta NC \text{ Position}_{m,t+}$ for all i. $I^{\text{limit}}_{i,m,t}$ is an indicator variable for limit occurrence for either limit up or limit down: $I^{\text{limit}}_{i,m,t} = I^{\text{up}}_{i,m,t}, I^{\text{down}}_{i,m,t}$. If price limits served to reduce speculation, we expect a positive coefficient on $I^{\text{up}}_{i,m,t}$ for changes in long positions, and a positive coefficient on $I^{\text{down}}_{i,m,t}$ for changes in short positions. Controls include the lagged change in noncommercial long and short positions ($\Delta NCL_{i,m,t-}$, $\Delta NCS_{i,m,t-}$) and daily returns ($r_{i,m,t-1}$, $r_{i,m,t-2}$, $r_{i,m,t-3}$). FE_t and FE_m are time and commodity fixed effects used to capture unobserved heterogeneity across commodities and time unrelated to our variables of interest. We report the regression results in Table 3.

Noncommercial market participants do not reduce their long positions after a limit up, but they do reduce their long positions after a limit down by about 0.9% of the prevailing open interest. Their short positions are reduced by 0.5% after a limit up but not after a limit down. Interestingly, increases in long (short) positions are likely followed by further increases in long (short) positions, but increases in short (long) positions are likely succeeded by decreases in long (short) positions. Noncommercials as a whole act as momentum traders: They add to their long positions and cut their short positions when past returns are high (Kang, Rouwenhorst, & Tang, 2017; Moskowitz et al., 2012).

Although lagged position changes and lagged commodity returns are significant predictors of future position changes, the predictive coefficients of the indicator variables for limit events are virtually unchanged across specifications including different control variables. Furthermore, the point estimates for the effect of price limits in Table 3 are nearly identical to the estimates in Table 2, which further demonstrate the strong predictive power of price limits on noncommercial position changes.

The multivariate analysis in Table 3 complements our univariate analysis in Table 2 in showing that price limits are not effective in reducing speculation. Speculative pressure further builds in the direction of price limits: Noncommercials become more net long following limit up events and more net short following limit down events. Noncommercial market participants appear to reduce their positions after losses following large price moves, not in response to price limits occurring.

4 | A FUNDAMENTALS-BASED EXPLANATION OF LIMIT EVENTS

4.1 | Changes in trader positions preceding limit events

If speculation leads to limits, speculators should actively trade just before limit events. Limit up events should be preceded by increased long positions and limit down events preceded by increased short positions. Higher trading before limits are reflected in position changes. To measure the trading behavior of speculators, we calculate the change in noncommercial positions for the two nearest COT reports before limit events. As before, long and short positions are scaled by open interest. Tables 4 and 5 present the results.

The first row shows that before limit up events, noncommercials do not add to their long positions. Instead, 8 of the 12 commodities experienced decreased long positions. Similarly, before limit down events, noncommercials do not increase their short positions. On average, there is no change for either long or short positions before limit events across commodities. For comparison, we also look at trading behavior before 90% moves. Noncommercial position changes before 90% up moves closely resemble those for limit up events, and 90% down moves results look like those for limit down events. In all cases, there does not appear to be heavy directional trading before limits or large moves.

TABLE 3 The effect of price limits on noncommercial position changes

***LHV* = Δ *NCL*$_{i,m,t+}$**							***LHV* = Δ *NCS*$_{i,m,t+}$**						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**		**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
γ	0.001 (0.1)	0.002 (0.3)	0.005 (0.5)	0.006 (0.7)	0.008 (0.9)	0.009 (1.0)	γ	0.013 (1.4)	0.012 (1.2)	0.012 (1.2)	0.010 (1.1)	0.015 (1.6)	0.013 (1.4)
$I^{up}_{i.m,t}$	−0.019 (0.2)		0.004 (0.1)		−0.057 (−0.3)		$I^{up}_{i,m,t}$	**−0.523** (−3.8)		**−0.531** (−3.9)		**−0.466** (−3.6)	
$I^{down}_{i,m,t}$		**−0.928** (−5.9)		**−0.880** (−5.8)		**−0.790** (−6.1)	$I^{down}_{i,m,t}$		0.058 (0.5)		0.028 (0.2)		−0.060 (−0.5)
Δ $NCL_{i,m,t-}$			**9.652** (15.1)	**9.620** (15.0)	**9.312** (13.8)	**9.277** (13.7)	Δ $NCL_{i,m,t-}$			**−6.929** (−9.1)	**−6.916** (−9.1)	**−5.514** (−6.8)	**−5.503** (−6.8)
Δ $NCS_{i,m,t-}$			**−7.833** (−12.4)	**−7.841** (−12.4)	**−6.921** (−10.4)	**−6.931** (−10.5)	Δ $NCS_{i,m,t-}$			**18.045** (23.8)	**18.052** (23.8)	**17.558** (22.0)	**17.565** (22.0)
$r_{i,m,t-1}$					**18.928** (18.6)	**18.816** (18.5)	$r_{i,m,t-1}$					**−21.956** (−15.3)	**−22.007** (−15.3)
$r_{i,m,t-2}$					**16.157** (15.8)	**16.168** (15.9)	$r_{i,m,t-2}$					**−19.415** (−13.5)	**−19.410** (−13.5)
$r_{i,m,t-3}$					**12.531** (12.2)	**12.542** (12.3)	$r_{i,m,t-3}$					**−15.851** (−11.0)	**−15.840** (−11.0)
N	635,040	635,040	635,040	635,040	635,040	635,040	N	635,040	635,040	635,040	635,040	635,040	635,040
Commodity FE	Y	Y	Y	Y	Y	Y	Commodity FE	Y	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y	Y	Time FE	Y	Y	Y	Y	Y	Y

Note. The output from the following regression specification is:

$$\Delta NC\ \text{Position}_{i,m,t+} = \gamma + \beta^{\text{limit}} I^{\text{limit}}_{i,m,t} + \text{Controls} + FE_t + FE_m + \varepsilon_{i,m,t+},$$

where $\Delta NC\ \text{Position}_{i,m,t+} = \Delta NCL_{i,m,t+}$, $\Delta NCS_{i,m,t+}$ is the change in noncommercial long or short position after a price limit at time t, for commodity m, and contract i. CFTC does not separately report positions by contract, so $\Delta NC\ \text{Position}_{i,m,t+} = \Delta NC\ \text{Position}_{m,t+}$ for all i. $I^{\text{limit}}_{i,m,t}$ is an indicator variable for limit occurrence for either limit up or limit down: $I^{\text{limit}}_{i,m,t} = I^{\text{up}}_{i,m,t}, I^{\text{down}}_{i,m,t}$. Controls include the lagged change in noncommercial long and short positions ($\Delta NCL_{i,m,t-}$, $\Delta NCS_{i,m,t-}$) and daily returns ($r_{i,m,t-1}$, $r_{i,m,t-2}$, $r_{i,m,t-3}$). FE_t and FE_m are time and commodity fixed effects. Coefficients are multiplied by 100. t-Statistics clustered by commodity and by time are shown in parentheses. Significance at the 5% level is shown in bold. The sample is from January 07, 1991 to May 23, 2016.

TABLE 4 Changes in noncommercial positions before limit days

	BO	C	CT	FC	KW	LC	LH	O	RR	S	SM	W	ALL
	Δ Noncommercial long positions before limits												
Average (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Limit up	−0.5%	−0.1%	−0.1%	**−0.4%**	0.0%	−0.2%	0.0%	0.4%	0.0%	−0.1%	−0.1%	−0.3%	−0.1%
	(−1.4)	(−0.8)	(−0.8)	(−2.1)	(0.0)	(−0.9)	(−0.1)	(1.1)	(0.0)	(−0.5)	(−0.1)	(−1.5)	(−1.9)
N	146	165	480	414	122	236	259	113	322	107	112	144	2,620
Limit down	−0.4%	−0.1%	**−0.5%**	**−0.5%**	0.3%	0.3%	−0.1%	**1.0%**	−0.5%	−0.3%	0.0%	0.1%	−0.1%
	(−1.3)	(−0.8)	(−2.9)	(−2.5)	(1.5)	(1.3)	(−0.6)	(3.2)	(−1.7)	(−1.1)	(−0.1)	(0.4)	(−1.6)
N	194	199	397	622	69	299	256	149	370	195	154	77	2,981
	Δ Noncommercial short positions before limits												
Average (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Limit up	0.2%	−0.1%	**−0.4%**	0.1%	−0.2%	0.0%	−0.3%	0.4%	0.2%	−0.2%	−0.9%	**−0.3%**	−0.1%
	(0.8)	(−0.6)	(−3.5)	(0.8)	(−1.7)	(0.1)	(−1.5)	(1.2)	(1.3)	(−0.8)	(−1.2)	(−2.0)	(−1.5)
N	146	165	480	414	122	236	259	113	322	107	112	144	2,620
Limit down	**0.3%**	−0.2%	−0.1%	−0.1%	0.2%	0.0%	−0.1%	**0.7%**	0.2%	−0.4%	−0.1%	−0.2%	0.0%
	(2.3)	(−1.2)	(−0.9)	(−0.6)	(0.7)	(0.4)	(−0.5)	(2.2)	(0.6)	(−1.4)	(−0.5)	(−1.4)	(−0.3)
N	194	199	397	622	69	299	256	149	370	195	154	77	2,981

Note. BO: soybean oil; C: corn; CFTC: Commodity Futures Trading Commission; COT: Commitment of Traders; CT: cotton; FC: feeder cattle; KW: Kansas City wheat; LC: live cattle; LH: lean hogs; O: oats; RR: rough rice; S: soybean; SM: soybean meal; W: soft red winter wheat.
The change in the positions of noncommercial market participants before limit days is reported. Long and short positions of noncommercials from the CFTC COT report are scaled by the open interest "limit up" and "limit down" report the change in scaled positions in the two reports before limit up and limit down events. We test for the equality of average positions and positions after limit events, and report White (1980) t-statistics in parentheses. Significance at the 5% level is shown in bold. The sample is from January 07, 1991 to May 23, 2016.

If speculative positions do not cause price limits to occur, what does? We hypothesize that limit events are more likely to be associated with changing fundamentals. We find support of this hypothesis in implied volatility, commodity fundamentals, and price behavior around limit events.

4.2 | Implied volatility around limit events

Limits events are obviously evidence of elevated volatility. If volatility is driven by speculative activity and price limits curb speculation, subsequent volatility is expected to fall as suggested by Ma et al. (1989). Alternatively, if volatility reflects commodity fundamentals that are persistent, we would expect comparable levels of volatility before and after price limits.

TABLE 5 Futures basis before limit days

	BO	C	CT	FC	KW	LC	LH	O	RR	S	SM	W	ALL
Average (%)	−1.95	−2.73	−2.95	1.53	1.35	0.23	0.78	−6.29	−3.20	4.09	5.83	−2.71	
	Limit up												
Day before	−3.83%	**24.42%**	**16.11%**	**12.47%**	2.62%	**9.04%**	−3.61%	5.19%	−3.61%	18.10%	**31.89%**	3.98%	**12.96%**
	(−1.1)	(2.2)	(6.0)	(3.1)	(0.4)	(2.1)	(−0.6)	(1.9)	(−0.1)	(1.0)	(2.4)	(0.7)	(5.4)
	Limit down												
Day before	**−6.29%**	19.31%	**12.15%**	**11.83%**	5.55%	**12.55%**	**−23.72%**	**10.48%**	−2.26%	15.94%	39.71%	6.40%	**10.44%**
	(−3.1)	(1.6)	(4.0)	(3.7)	(0.7)	(2.8)	(−2.6)	(2.3)	(0.3)	(1.3)	(1.9)	(0.8)	(4.7)

Note. BO: soybean oil; C: corn; CT: cotton; FC: feeder cattle; KW: Kansas City wheat; LC: live cattle; LH: lean hogs; O: oats; RR: rough rice; S: soybean; SM: soybean meal; W: soft red winter wheat.
The basis of the futures curves is presented. The futures basis is calculated as the annualized price difference between the nearest and second nearest futures contracts. t-Statistics for individual commodities are calculated from the unconditional average basis using White (1980) standard errors. t-Statistics for the "ALL" column are calculated with commodity fixed effects and clustered by commodity and time. Significant values at the 5% level are shown in bold. The sample is from January 07, 1991 to May 23, 2016.

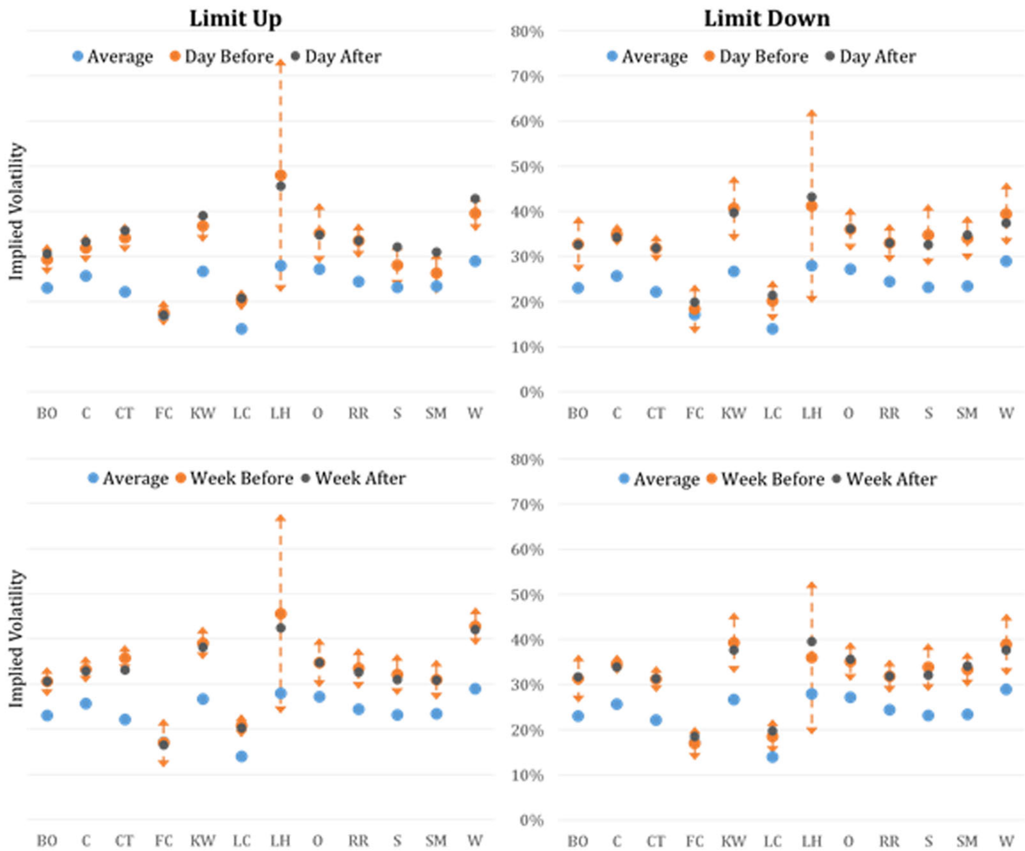

FIGURE 3 Implied volatility around limit days. It shows the implied volatility of options on futures contracts. Implied volatilities calculated using the Black (1976) model are obtained from Commodity Research Bureau. The blue dots show the unconditional averages. The gold dots show the average implied volatility before limits events, and the gold dashed lines and arrows show the 95% confidence interval. The gray dots show the average implied volatility after limit events. The sample is from January 07, 1991 to May 23, 2016 [Color figure can be viewed at wileyonlinelibrary.com]

The difficulty in testing these hypotheses lies in that using prices restricted by limits to calculate volatility leads to mismeasurement (Miller, 1989). If we include returns on limit days in our volatility calculation, realized volatility is mechanically biased downwards. If we exclude consecutive limit days and only focus on the 1-day limit events, we only consider small price moves and induce further downward bias in volatility estimates. Miller (1989) viewed this problem as a "possibly insuperable obstacle." We circumvent this issue by using implied volatility instead of realized volatility. Because options markets almost rarely hit limits, even if the underlying futures market does, implied volatility does not suffer from the same selection bias as in the futures markets.[9]

We present implied volatility before and after limit events in Figure 3. Two observations stand out. First, implied volatilities are significantly higher around limit days compared to their unconditional averages; limits are more likely occur when volatility is elevated. For all 12 commodities, implied volatility on the day before limits events is higher than its unconditional mean. This pattern also holds for the average implied volatility in the week before limit events.

Second, volatility after limit events is not significantly lower than its prelimit level. We show the 95% confidence interval for implied volatility before limit events with gold dashed lines. For all 12 commodities, implied volatility on the day after limit events is not statistically different from the implied volatility on the day before the events. These findings also hold for average implied volatility if we broaden the interval of volatility measurement to one the week before and after limit events.

Our results reflect the importance of proper volatility estimation emphasized by Miller (1989). They stand in sharp contrast to Ma et al. (1989) who document a decline in realized volatility after price limits. Combined with our findings

[9]Historically, some options have had price limits equivalent to limits on the underlying futures (e.g., $3 price limit in both futures and options). Because ATM options have deltas less than one, on futures limit days the associated ATM options rarely hit limits and continued to trade.

for speculator positions, the evidence suggests price limits are not a result of excess volatility from speculation, but rather occur for fundamental reasons.

4.3 | Commodity fundamentals

Deaton and Laroque (1992) show that low physical inventories are associated with stock-out risk and elevated price volatility. Elevated price volatility increases the likelihood that price limits are hit. Gorton, Hayashi, and Rouwenhorst (2013) provide empirical evidence that low inventories are associated with high convenience yields and "backwardated" futures curves. We calculate the futures basis, using the nearest-to-maturity contract and the second nearest contract, and examine how commodity fundamentals may be related to price limits. The fundamental explanation for limits predicts that limit events are likely preceded by an elevated futures basis.

For 9 of the 12 commodities, both limit up and limit down events are preceded by backwardation. In particular, corn, cotton, feeder cattle, live cattle, soybean, and soymeal all exhibit steep backwardation before limit events, although statistical significance at the commodity level varies across commodities due to the variability of the basis and the number of limit events. We pool all of the commodities in the "ALL" column to reduce noise and improve statistical power. Across commodities, backwardation is observed before both limit ups and limit downs.

These findings are broadly consistent with the fundamental explanation for the occurrence of price limits although individual commodity results are noisy. The largest outlier is for lean hogs before limit down events. Limit down events for lean hogs occurred during times of disease. These disease episodes affected inventory and raised stock-out concerns but were not entirely reflected in the basis.[10]

4.4 | Price continuation following limit events

If limit events occur due to a shift in commodity fundamentals, any related price effects will likely persist. If limits merely curb speculative trading price effects are likely to mean revert over time. We investigate price behavior around limits, treating limit days as "events," and trace out average returns on subsequent days. The existing literature has debated the presence of continuations or reversals by examining returns on the day following the limit event (Evans & Mahoney, 1996, 1997; Hall et al., 2006; Reiffen & Buyuksahin, 2010; Reiffen et al., 2006). One-day returns will obviously identify immediate return reversals, but do not distinguish persistent price effects from price reversals that take several days to unfold. For this reason, we widen our focus to the returns over the 2 weeks following a limit event.

The results are summarized in Figure 4. After a limit up event ($t = 0$), the next-day return ($t = 1$) is on average 56 basis points across 12 commodities. This estimate includes consecutive limit days. If we remove consecutive limit days, the average return is 29 basis points after a limit up event. Omitting consecutive limit days provides a conservative estimate for the degree of price continuation, so the 29 basis points can be viewed as a lower-bound value. While these findings shed some light on the debate of next-day continuations, for the purpose of our study the more important conclusion is these price continuations appear persistent; there is not much drift over the next 10 trading days. The 95% confidence interval excludes zero for all 10 days. Cumulative returns are 52 and 36 basis points after 10 days. This is consistent with the fundamental view of limit events.

Price continuation could be due to the time-series properties of returns. If returns were autocorrelated, we would expect to observe price continuation in Figure 4. If the following day returns are a function of large price moves rather than limits, then actual limit days and 90% move days should exhibit similar next-day returns. However, if limit days are different from large moves, we would expect different patterns.

Price behavior after limit up events is very different from 90% up moves. After a 90% up move, the average return on the following day is 3 basis points. Cumulative returns somewhat drift downwards, ending at −21 basis points after 2 weeks. The slight downward drift may be due to mean reversion in commodities returns (Bessembinder, Coughenour, Seguin, & Smoller, 1995). The bottom panels present the results for limit down events, which are almost mirror images of limit up events. The average returns on the day after a limit down event is −53 basis points for all limit days. It is −27 basis points if we only include nonconsecutive limit days. Cumulative returns show no reversal over the next 2 weeks.

[10]In April 2009, swine flu (also known as 2009 H1N1 flu) broke out in Canada. This caused the entire futures curve to collapse in fears that the available supply was unusable. As it became clear that only specific batches and regions were affected, the nearby and far out contracts rallied back. These price changes hit price limits both on the up and down sides, without a significant change in inventory or basis.

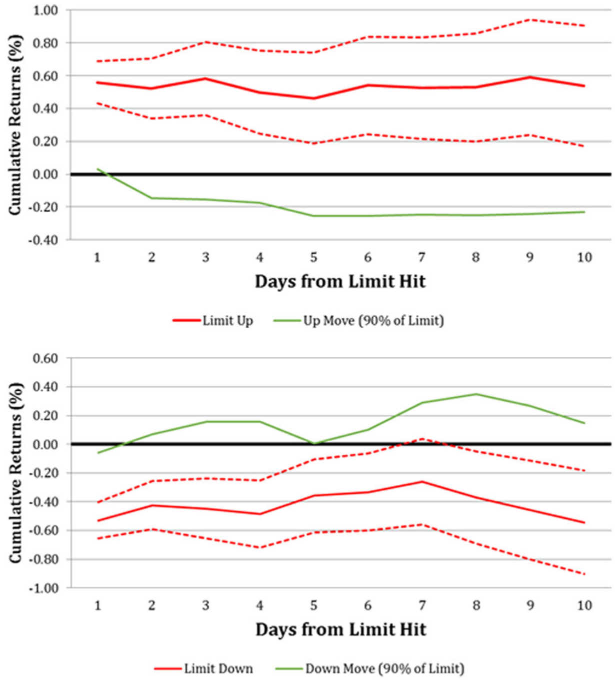

FIGURE 4 Cumulative returns around limit days. It plots the cumulative returns after a limit-day event. $t = 0$ marks the limit day. The red line averages across all limit up (top) or limit down (bottom) events, and the 95% confidence interval is shown with dashed red lines. As a comparison, we locate days in which price movements were between 90% and 100% of the limit but do not hit the limit. The green line shows average returns after the 90% limit moves. The sample is from January 07, 1991 to May 23, 2016 [Color figure can be viewed at wileyonlinelibrary.com]

For the 90% down moves, cumulative returns are close to zero immediately afterwards. There is also a small upward drift after 90% down moves.

Persistent price effects suggest fundamental volatility leads to price limits. Speculation is likely associated with excess volatility and price reversals. Price moves that persist for 2 weeks indicate prices have moved to new equilibrium levels. The price effects also suggest that price limits and large moves have different impact on price discovery. Price discovery is only restricted by limit events, because limits often occur for fundamental causes.

5 | PRICE DISCOVERY IN OPTIONS MARKETS

The behavior of prices and positions around limit events is consistent with the view that limit events are primarily the results of shocks to fundamentals that are persistent. Limits merely postpone price adjustments and therefore hinder price discovery when the incentives to do so are potentially large. Unlike futures contracts, options on commodity futures currently do not have price limits. Historically, some options have had limits that were almost never hit because the limits were as large as those for the underlying futures. As many market participants can easily access both markets, price discovery on limit days is likely to move from the futures market to the options market (Reiffen et al., 2006). We collect options prices on limit days when the futures market stops trading and examine the information contained in option-implied futures prices. In particular, we are interested in the question whether options markets provide an unbiased predictor of the next-day futures price when limits are hit.

Commodity options and futures prices are closely related through put–call parity (Black, 1976). Consider European call c_t and put p_t with strike price K, and their underlying futures price F_t. By the Law of One Price, the following relationship holds:

$$c_t - p_t = (F_t - K)B(t, T), \tag{2}$$

where $B(t, T)$ is the present value of a zero-coupon bond that matures to \$1 at time T. $B(t, T)$ discounts time T cash flows F_t and K to time t. We can rearrange (2) to isolate F_t:

TABLE 6 Options-implied forecasts of next-day futures returns

	BO	C	CT	FC	KW	LC	LH	O	RR	S	SM	W	ALL
a	−0.14%	0.00%	−0.05%	0.09%	0.42%	0.04%	−0.25%	−0.17%	0.03%	−0.18%	−0.05%	**0.31%**	0.00%
	(−0.62)	(0.00)	(−0.55)	(1.02)	(0.54)	(0.50)	(−1.66)	(−0.35)	(0.12)	(−0.78)	(−0.16)	(1.99)	(−0.06)
b	0.79	0.63	**0.65**	**0.39**	0.45	**0.39**	0.96	1.07	1.20	**0.15**	0.74	**0.36**	**0.80**
	(−1.07)	(−1.36)	(−4.54)	(−7.19)	(−0.39)	(−6.88)	(−1.64)	(0.42)	(1.62)	(−5.99)	(−1.09)	(−3.50)	(−2.67)
F test	0.27	0.23	0.00	0.00	0.10	0.00	0.07	0.19	0.00	0.00	0.28	0.00	0.00
N	114	198	390	318	62	179	221	83	257	126	93	178	2,219
R^2 (%)	22.6	40.2	51.2	38.8	2.0	49.2	94.1	82.9	82.4	8.1	18.2	23.6	68.6

Note. BO: soybean oil; C: corn; CT: cotton; FC: feeder cattle; KW: Kansas City wheat; LC: live cattle; LH: lean hogs; O: oats; RR: rough rice; S: soybean; SM: soybean meal; W: soft red winter wheat.
Regressions using options-implied returns to forecast next-day returns are presented. Option-implied futures prices $F_{i,m,t}^{\text{implied}}$ are calculated using put–call parity. Options-implied returns are calculated as

$$r_{i,m,t}^{\text{implied}} = (F_{i,m,t}^{\text{implied}}/F_{i,m,t}^{c}) - 1,$$

where $F_{i,m,t}^{c}$ is the closing futures price on the limit day t. We run the following regression:

$$r_{i,m,t+1}^{c,o} = a + br_{i,m,t}^{\text{implied}} + \eta_{i,m,t+1}^{c,o},$$

where $r_{i,m,t+1}^{c,o} = (F_{i,m,t+1}^{o}/F_{i,m,t}^{c}) - 1$ is the close-to-open return from the limit-day closing price to the next-day opening price for contract i of commodity m. t-Statistics clustered by time are shown in parentheses. For a, t-statistics are calculated from zero, and for b, t-statistics are calculated from 1.0. Significant values at the 5% level are shown in bold. "F test" provides the p-value for the joint test that $a = 0$ and $b = 1$. "N" is the number of observations for each regression. The sample is from January 07, 1991 to May 23, 2016.

$$F_t = K + \frac{c_t - p_t}{B(t, T)}. \tag{3}$$

Commodity options generally permit early exercise, in which case (3) becomes a bound rather than an equality. Although early exercise may be optimal for American options, Ramaswamy and Sundaresan (1985) show that the value of early exercise is small for options on futures, such that an American option can be closely approximated using the Black (1976) model and (3) still holds. On limit days, we use the Citigroup 3-month Treasury Bill Index to calculate the interest rate for $B(t, T)$, and the ATM put and call to compute the option-implied futures price.

5.1 | Forecasting futures prices

If price discovery moves from the futures market to the options market, option-implied futures prices should forecast next-day futures prices when trading resumes. We test this hypothesis with forecasting regressions. Although the hypothesis calls for regressing actual prices on implied prices, this will lead to a spurious regression because prices contain a unit root. To circumvent this problem, we examine the forecasting relationship using returns instead of prices. Let $F_{i,m,t+1}^{o}$ be the opening price of day $t+1$ and $F_{i,m,t}^{c}$ be the closing price of t for contract i of commodity m. Let $F_{i,m,t}^{\text{implied}}$ be the option-implied futures price on day t. We run the following regression:

$$r_{i,m,t+1}^{c,o} = a + br_{i,m,t}^{\text{implied}} + \eta_{i,m,t+1}^{c,o}, \tag{4}$$

where $r_{i,m,t}^{\text{implied}} = (F_{i,m,t}^{\text{implied}}/F_{i,m,t}^{c}) - 1$ is the option-implied futures return and $r_{i,m,t+1}^{c,o} = (F_{i,m,t+1}^{o}/F_{i,m,t}^{c}) - 1$ is the futures returns from the limit-day closing price to the next-day opening price. If $r_{i,m,t}^{\text{implied}}$ is an unbiased predictor of the next-day returns, we expect to see $a = 0$, $b = 1$. These values form our null hypothesis. Furthermore, if the forecast is accurate, we expect the regression R^2 to be high (Mincer & Zarnowitz, 1969).

Table 6 presents the forecasting results. For individual commodity regressions, intercepts are statistically indistinguishable from zero except for wheat. Slope coefficients are all positive, and 7 of the 12 slopes are statistically

TABLE 7 Migration of open interest from futures to options markets

	Δ Ratio of open interest												
Coefficient × 100	**BO**	**C**	**CT**	**FC**	**KW**	**LC**	**LH**	**O**	**RR**	**S**	**SM**	**W**	**ALL**
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limit up	**0.83**	**2.22**	**5.31**	**−1.23**	0.09	−0.09	**0.94**	−0.12	**0.18**	**4.56**	**1.08**	**2.30**	**1.30**
	(2.0)	(4.3)	(5.7)	(−3.5)	(0.2)	(−0.2)	(3.9)	(−0.9)	(2.0)	(5.4)	(2.7)	(3.9)	(6.4)
Limit down	**1.75**	0.34	0.69	**3.53**	**0.47**	**1.73**	0.60	−0.13	**−0.29**	0.69	**0.86**	**1.60**	**1.29**
	(5.8)	(0.5)	(0.7)	(6.7)	(5.0)	(3.1)	(1.9)	(−1.0)	(−2.0)	(1.0)	(3.4)	(3.8)	(6.7)

Note. BO: soybean oil; C: corn; CT: cotton; FC: feeder cattle; KW: Kansas City wheat; LC: live cattle; LH: lean hogs; O: oats; RR: rough rice; S: soybean; SM: soybean meal; W: soft red winter wheat.
The change in the ratio of open interest is shown. We calculate this ratio as the combined futures and options positions divided by the open interest of futures-only positions. "Δ Ratio of open interest" is the difference in this ratio. "Average" reports the unconditional averages of this ratio. "Limit up" and "limit down" report the average change in this ratio around limit up and limit down events. Coefficients are multiplied by 100. White (1980) t-statistics are reported in parentheses.

and economically indistinguishable from one. The rightmost column shows a pooled regression including all 12 commodities. The pooled intercept is small and insignificantly different from zero. The pooled slope estimate is 0.80, indicating that a 1% increase in the return calculated using the implied futures price is associated with a 0.8% increase in the close-to-open return after the limit day. We cannot reject the null hypothesis that option-implied returns are unbiased predictors of close-to-open returns for 5 of the 12 commodities. For the pooled regression, which has more power than commodity-level regressions, we reject the null.

Table 6 shows that the slope coefficient b is often less than one: The option-implied price on average overshoots its target. While overshooting can indicate an overreaction, a possible alternative explanation is based on risk-bearing capacity of market makers. When a futures market hits a price limit, trading stops and volume migrates to the corresponding options market. For a limit up event, traders trying to establish a long position would lead to demand for calls. If market makers have limited capacity to absorb this new buying pressure, the sudden increase in demand pushes the call prices up relative to the puts (Bollen & Whaley, 2004). The option-implied futures price will then appear to be too high compared to the unconstrained futures price.

Similarly, for a limit down event, the selling pressure combined with the increase in liquidity demand pushes the put prices further down than the calls, and the implied price appears to be too low relative to the unconstrained price. In both cases, the option-implied futures price overshoots the price that would have prevailed in the absence of limits. Our results are consistent with the interpretation that price discovery moves from the futures markets to the associated options markets on limit days, but limited risk capacity of market makers combined with unbalanced demand for puts and calls can push option-implied futures prices too far in the same direction as limit moves.

Our results have some similarities to Reiffen et al. (2006) and Reiffen and Buyuksahin (2010), who also study the information content in options prices in a subsample of ours. However, there are some notable differences. They generally reject unbiasedness ($a = 0$; $b = 1$) of the option-implied futures prices, finding large intercepts and coefficients unequal to one in their forecasting regressions. In contrast, we do not reject unbiasedness for 5 of the 12 commodities we examine, and we generally find a statistically and economically small intercept for all commodities.

5.2 | Migration of trading to options markets

If market participants switch from futures to options, we expect to see the open interest in options market increase relative to the futures market after limit days. The CFTC COT report distinguishes between futures and options market participants in two reports—one for futures only and another that includes delta-adjusted options positions along with futures. We divide the open interest of futures and options by the open interest of futures-only positions and use this ratio as a measure of relative activity in the two markets. We then calculate the change in this ratio around limit events. The results are reported in Table 7.

On average, there is no change in the ratio of open interests. The number of options positions relative to the number of futures positions does not exhibit any trends. Consistent with the hypothesis that trading activity migrates to the options market when the futures market hits price limits, this ratio increases after both limit up and limit down events. After limit up events, the ratio of open interests increases on average by 1.3%. Nine of the 12 commodities have increased ratios. For limit down events, the ratio increases by 1.3% across commodities, with 10 of the 12 commodities showing increases. Our findings are consistent with those of Evan and Mahoney (1997), who examine the corn market during 20 trading days in September 1995 and find that trading volume moves from futures to options on limit days. We document a similar pattern across a variety of commodities.

6 | CONCLUSION

The historical justification for the existence of price limits is to curb speculation. In this paper, we re-examine the role of price limits by studying trader positions and price behavior around limit events for 12 commodities over a 25-year period and offer three main findings:

First, limits do not appear to be effective in reducing speculative trading behavior. After limit up events, noncommercial traders do not change their long positions and reduce their short positions, resulting in increased net long positions. After limit down events, noncommercial traders do not change their short positions and reduce their long positions, leading to increased net short positions. This response is similar to the adjustment of trader positions on nonlimit days with large price movements: Traders cut losses on positions that lost money. Moreover, we do not find evidence of unusual directional trading by noncommercial traders in the week before a limit event, suggesting that the occurrence of limits events is for reasons unrelated to position changes.

Second, we present several pieces of evidence that links the occurrence of limits to elevated volatility that is driven by fundamentals. We provide direct evidence of increased volatility around limit days, which coincides with an elevated basis for the underlying commodities, indicating elevated risk of a stock-out. Persistent price continuations after limit events provide further evidence that changes in fundamentals are associated with increased fundamental volatility.

Third, limits hamper price discovery. On days following limit events, prices persistently trade outside the bounds set by these limits. This suggest that limits merely postpone price adjustment at a time when the incentive to do so is high. We show that price discovery and trader positions migrate to options markets. Options markets do not offer a perfect substitute for futures trading provide based on the finding that the option-implied futures prices provide a biased estimate of subsequent futures prices when the market reopens.

ACKNOWLEDGMENTS

We are grateful to Hank Bessembinder, Geetesh Bhardwaj, Colin Carter, Ing-Haw Cheng, Christopher Gilbert, Don Keim, Kurt Nelson, Ashraf Rizvi, Michel Robe, Kevin Sheehan, Jim Smith (Oklahoma discussant), Hilary Till (Oxford discussant), Andrei Kirilenko (JPMCC discussant) as well as participants at the 2017 Commodity and Energy Markets Annual Meeting in Oxford, the 2017 University of Oklahoma Energy and Commodities Finance Research Conference, and the 22nd JPMCC International Commodities Symposium. Rouwenhorst acknowledges the financial support of a Distinguished Visiting Fellowship offered by the J.P. Morgan Center for Commodities at the University of Colorado Denver. The views expressed are those of the individual authors and do not necessarily reflect official positions of SummerHaven Investment Management, LLC or Paraconic Technologies.

ORCID

Rajkumar Janardanan http://orcid.org/0000-0003-2034-9536
Xiao Qiao http://orcid.org/0000-0002-1274-175X
K. Geert Rouwenhorst http://orcid.org/0000-0002-5003-6031

REFERENCES

Bessembinder, H. (1992). Systematic risk, hedging pressure, and risk premiums in futures markets. *Review of Financial Studies*, *5*, 637–667.

Bessembinder, H., Coughenour, J. F., Seguin, P. J., & Smoller, M. M. (1995). Mean reversion in equilibrium asset prices: Evidence from the futures term structure. *Journal of Finance*, *50*, 361–375.

Black, F. (1976). The pricing of commodity contracts. *Journal of Financial Economics*, *3*, 167–179.

Bollen, N. P., & Whaley, R. E. (2004). Does net buying pressure affect the shape of implied volatility functions? *Journal of Finance*, *59*, 711–753.

Cheng, I. H., Kirilenko, A., & Xiong, W. (2014). Convective risk flows in commodity futures markets. *Review of Finance*, *19*, 1733–1781.

Deaton, A., & Laroque, G. (1992). On the behaviour of commodity prices. *Review of Economic Studies*, *59*, 1–23.

Ederington, L., & Lee, J. H. (2002). Who trades futures and how: Evidence from the heating oil futures market. *Journal of Business*, *75*, 353–373.

Evans, J. & Mahoney, J. M. (1996). *The effect of daily price limits on cotton futures and options trading* (Working Paper No. 9627). New York: Federal Reserve Bank of New York. https://EconPapers.repec.org/RePEc:fip:fednrp:9627

Evans, J., & Mahoney, J. M. (1997). The effects of price limits on trading volume: A study of the cotton futures market. *Current Issues in Economics and Finance*, *3*.

Gorton, G. B., Hayashi, F., & Rouwenhorst, K. G. (2013). The fundamentals of commodity futures returns. *Review of Finance*, *17*, 35–105.

Hall, A. D., Kofman, P., & Manaster, S. (2006). Migration of price discovery in semiregulated derivatives markets. *Journal of Futures Markets: Futures, Options, and Other Derivative Products*, *26*, 209–241.

Howell, L. D. (1934). *Fluctuations in prices of cotton futures contracts* (No. 164378). Technical Bulletins, United States Department of Agriculture, Economic Research Service. https://EconPapers.repec.org/RePEc:ags:uerstb:164378

Kang, W., Rouwenhorst, K. G., & Tang, K. (2017). *A tale of two premiums: The role of hedgers and speculators in commodity futures markets* (Working Paper No. 14-24). Yale International Center for Finance. https://ssrn.com/abstract=2449315; http://dx.doi.org/10.2139/ssrn.2449315

Kim, K. A., & Rhee, S. (1997). Price limit performance: Evidence from the Tokyo stock exchange. *Journal of Finance*, *52*, 885–901.

Kyle, A. S. (1988). Trading halts and price limits. *Review of Futures Markets*, *7*, 426–434.

Lehmann, B. N. (1989). Commentary: Volatility, price resolution, and the effectiveness of price limits. *Journal of Financial Services Research*, *3*, 205–209.

Ma, C. K., Rao, R. P., & Sears, R. S. (1989). Volatility, price resolution, and the effectiveness of price limits. *Journal of Financial Services Research*, *3*, 165–199.

Miller, M. H. (1989). Commentary: Volatility, price resolution, and the effectiveness of price limits. *Journal of Financial Services Research*, *3*, 201–203.

Mincer, J. A., & Zarnowitz, V. (1969). The evaluation of economic forecasts, *Economic forecasts and expectations: Analysis of forecasting behavior and performance* National Bureau of Economic Research, Inc, pp. 3-46. https://EconPapers.repec.org/RePEc:nbr:nberch:1214

Moser, J. T. (1990). Circuit breakers. *Economic Perspectives*, *14*, 2–13.

Moskowitz, T. J., Ooi, Y. H., & Pedersen, L. H. (2012). Time series momentum. *Journal of Financial Economics*, *104*, 228–250.

Ramaswamy, K., & Sundaresan, S. M. (1985). The valuation of options on futures contracts. *Journal of Finance*, *40*, 1319–1340.

Reiffen, D., & Buyuksahin, B. (2010). The puzzle of privately-imposed price limits: Are the limits imposed by financial exchanges effective? *Aestimatio*, *1*, 110–143.

Reiffen, D., Buyuksahin, B., & Haigh, M. S. (2006). Do price limits limit price discovery in the presence of options? https://ssrn.com/abstract=928013; http://dx.doi.org/10.2139/ssrn.928013

De Roon, F. A., Nijman, T. E., & Veld, C. (2000). Hedging pressure effects in futures markets. *Journal of Finance*, *55*, 1437–1456.

Schaede, U. (1989). Forwards and futures in tokugawa-period Japan: A new perspective on the Dojima rice market. *Journal of Banking and Finance*, *13*, 487–513.

White, H. (1980). A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica*, *4*, 817–838.

How to cite this article: Janardanan R, Qiao X, Rouwenhorst KG. On commodity price limits. *J Futures Markets*. 2019;39:946–961. https://doi.org/10.1002/fut.21999