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**GMO Contamination Price Effects in the U.S. Corn Market:  
StarLink and MIR162**

**Xue Han**

Department of Agricultural and Consumer Economics,  
University of Illinois at Urbana-Champaign  
xuehan3@illinois.edu

**Philip Garcia**

Department of Agricultural and Consumer Economics,  
University of Illinois at Urbana-Champaign  
p-garcia@illinois.edu

*Selected Paper prepared for presentation at the 2016 Agricultural & Applied Economics Association  
Annual Meeting, Boston, Massachusetts, July 31-August 2*

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## **Abstract**

While genetically modified technology has been investigated extensively, few studies have examined the price impact of genetically modified food contamination events. This paper contributes to the literature by examining the price effects of multiple genetically modified contamination events in the U.S. corn market. Using the relative price of substitute method and time-varying cointegration, we identify three structural breaks relevant to the corn contamination events, with the two largest being associated with StarLink and MIR162. Our results support the StarLink's large effect on corn prices, but the effect attributed to MIR162 is less clear. This more recent break in prices emerged three months prior to China's import ban, and was influenced by changes in U.S. corn supply, and EPA's proposed reduction of the ethanol mandate. Expansion of sorghum exports and subsequent increased corn production likely kept pressure on corn prices. While China's import ban on MIR162 may have influenced prices, evidence suggests the recent downturn in the U.S. corn market has been mainly caused by other domestic supply and demand changes.

**Keywords:** corn, sorghum, cointegration, GMO

JEL codes: Q13, Q11

## **Introduction**

Starting in November 2013, China rejected more than 850,000 metric tons of U.S. corn containing the genetically modified (GM) MIR162. According to a National Grain and Feed Association (NGFA)'s analysis in April 2014, this trade disruption cost the U.S. corn, distiller's dried grains (DDGS) and soy sectors between \$1 billion and \$2.9 billion in economic losses. MIR162 is a GM trait developed by Syngenta. The company has been sued by Cargill, American corn farmers, and others citing financial damages due to the import ban. Since China is the third largest U.S. corn importer, the MIR162 event could have significantly affected the U.S corn market.

Since 1996, GM corn varieties have been commercially available. The desired traits of genetically modified organisms (GMOs) including time- and cost-efficiency, insect (or bacteria) resistance and herbicide tolerance have stimulated their adoption by producers which has significantly increased supply and lowered production costs. The potential benefits of GMOs to producers, consumers, and the environment are large, although controversy on commercial production and marketing of GM foods has increased, especially in Europe and Asian countries. Several countries have banned or cancelled/rejected U.S. grain exports due to health concerns (Gadsby, 2001, p.5; Global Research News, 13 November 2014; BBC, 20 December 2013), resulting in potential losses to domestic corn producers.

The purpose of this paper is to examine the price impacts of multiple GM corn contamination events in the U.S. markets. Contaminations can result from mixing approved and unapproved crops in the market channel and by comingling seeds. To date, at least, ten GM corn contamination events have occurred in the U.S. (see Appendix A). The first, and most well-known, is the StarLink case. StarLink, approved only for feed and non-food industrial uses,

entered the human food supply in 2000. Carter and Smith (2007) show that the StarLink contamination reduced U.S. corn prices by 6.8 percent for at least one year. Price effects of the other corn contamination events have not been investigated, and only Li et al. (2010) has demonstrated a significant but brief effect of a GMO contamination in the U.S. rice market.

Two methods are used to assess the impacts of multiple GM corn contamination events in the U.S. corn market. Both examine the relative price relationship between corn and its close substitute sorghum. Following Carter and Smith (2007), a Bai-Perron structural break test, which is most appropriate in the presence of one event, is performed. While the Bai-Perron structural break test is designed for multiple-break situations, it assumes no shifts in the underlying time series. In the presence of multiple events, a price series is likely to experience multiple breaks that may result in shifts in series. As a result, we also adopt a time-varying cointegration procedure that has been used to examine the impact of multiple Bovine Spongiform Encephalopathy (BSE) events (Jin, Power and Elbakidze, 2008). The time-varying cointegration procedure allows shifts in the cointegrated relationship but is unlikely to provide precise break dates as the Bai-Perron test. We investigate the multiple break situations using these two complementary procedures.

We identify at least three structural breaks relevant to GM corn contamination events, including StarLink. Both methods suggest that the MIR162 event occurred near the largest and most protracted shock in relative prices. However, the findings indicate that the decline in prices began prior the MIR162 event. Separating the effect of the MIR162 event is complicated because other influential events coincided with MIR162. Time-line market evidence points to a break initially being influenced by changes in domestic corn and sorghum supply, and later by the EPA's proposed reduction of the ethanol mandate. Notably, the record high corn production in

2012/13 and 2013/14 had a dominant impact on the market. China's rejection of U.S. corn and its substantial increase of U.S sorghum imports appear to prolong the depressed situation in U.S. corn market to late 2014. Despite China's sharp reduction in the demand, U.S. exports of corn increased to a record high in 2014. Other U.S. corn buyers were attracted by the low corn prices, which contributed to the record high corn exports.

### **U.S. Corn Contamination Events**

The ten GM corn contamination events are listed chronologically in Table 1. Most of the GM corn contamination events had little impact on the U.S. corn market and therefore received little attention. The StarLink event was the first and the most well-known. Aventis CropScience, a multinational company based in France, developed StarLink corn. This corn variety, approved only for feed and non-food industrial uses, was not intended for human consumption due to its uncertain health effects. By 2000/01 marketing year, StarLink accounted for only 0.5 percent of the U.S. total corn production but 1.1 percent in Iowa. On September 18, 2000, the *Washington Post* reported that some taco shells containing a StarLink corn protein were sold in retail stores. This led to a recall by the manufacturer of nearly 300 food products. On October 11, 2000, a second recall was required as taco shells from Safeway food stores were found to contain traces of a StarLink protein. It is uncertain how StarLink corn was mixed with food corn though it may have occurred during storage or transportation. At the time, isolating and preventing unwanted commingled crops was difficult in the marketing system.

China has enforced a zero-tolerance policy on MIR162 traits in U.S. corn imports since the end of November 2013. MIR162 is Syngenta's biotechnology product that contains a Bt protein toxic to a variety of corn pests. It is approved in major markets including the EU, with the exception of China. On August 7, 2014, the National Grain and Feed Association (NGFA)

indicated that after MIR162 traits had been detected in U.S. exports, a series of trade disruptions occurred in the shipments of U.S. commodities, including corn, Dried Distillers Grains with Solubles (DDGS), and soybeans. Subsequently, China has almost completely banned U.S. corn from its feed grain markets. According to the NGFA's estimate, China's MIR162 rejection of U.S. shipments has cost the U.S. corn, DDGS and soy sectors between \$1 billion and \$2.9 billion in economic losses to April 22, 2014 (Farm Futures). The USDA's projection of 2013-2014 marketing year of U.S. corn to China was 7 million metric tons. However, only 1.23 million metric tons of corn had been shipped to China by April 22, 2014. In order to replace U.S. corn imports, China increased imports of U.S. grain sorghum, a substitute of corn, and acquired corn from other exporters.

On December 22, 2014, Syngenta confirmed that China finally agreed to accept imports containing MIR162 after the decision had been rumored for weeks. U.S corn prices have been increasing since October 2014 when rumor of the approval started. The central Illinois corn price closed at \$2.79/bu on October 1, 2014 and then peaked at \$3.86/bu on December 22nd, 2014 when Syngenta confirmed the approval. Since the sorghum prices went up as well, the relative prices did not go up significantly after October 2014.

China's price support policies play a critical role in its imports of grain. China's market prices have been distorted by the domestic support policies during the decade after China joined the World Trade Organization (WTO). Several years ago, China's authorities began to support farmers by means of price supports since their subsidy programs were unable to offset the impact of increasing production costs (Gale, Henson and Jewison, 2015). Authorities increased support prices every year from 2009 to 2013. Due to the record high corn harvest in 2013 and 2014 for both U.S. and China, corn prices fell sharply. China's authorities raised corn support prices,

which resulted in a larger gap between domestic and imported corn prices. As U.S. corn was banned due to MIR162, China significantly increased imports of sorghum, a substitute for corn. China's imports of sorghum soared to more than 340 million bushels, averaging 4.4 million bushels per week (*farmdoc daily*, January 26, 2015). Based on these changes in U.S exports of corn and sorghum, MIR162 may have had a significant impact on U.S. corn prices.

Other GM corn contamination events have received much less attention compared to StarLink and MIR162. Thus, we might expect the impacts of these events on the U.S. corn market to be weaker. GeneWatch UK identified eight other GM corn contamination events from news or reports. These eight events involve approved crops being commingled with GM corn varieties unapproved by U.S. food security organizations, such as the Food and Drug Administration (FDA), the American Medical Association, and the Environmental Protection Agency (EPA). Appendix A contains a brief description of all the ten events, including MIR162. Since this paper focuses only on the relative impact of Starlink and MIR162, the other eight events are not discussed in detail.

To date, StarLink is the only GM corn contamination event that has been empirically analyzed. Considerable research exists on price premiums that consumers are willing to pay for non-GM food rather than GM food, and on economic welfare effects of the introduction of GMOs into the food chain (Bullock and Desquilbet, 2002; Phipps and Park, 2002; Cases and de Lorenzo, 2010). Fewer studies are available on the potentially important negative effects of GMO contamination on actual market prices. To our knowledge, there are only two studies on pricing effects of GMO contaminations (Carter and Smith, 2007; Li et al., 2010). Carter and Smith (2007) investigate the price effects of a GM corn contamination event, StarLink. Using a relative price substitute (RPS) method and the Bai-Perron test, Carter and Smith find that



StarLink contamination reduced U.S. corn prices by about 6.8 percent for at least a year.

Following Carter and Smith's (2007) approach, Li et al. (2010) examine the impact of a GM rice contamination event, LL601, on prices and volume marketed in the U.S. and Thailand, the major rice export competitor. They find a large and adverse U.S. price reaction that persisted for a very short period (i.e. less than a month).

Although MIR162 is GM-related event like StarLink, market reactions to GM corn containment may differ due to the changes in market opportunities and technologies in the U.S. corn market. Since 2005, The Renewable Fuel Standard (RFS) has boosted demand for ethanol and thereafter has changed the use of corn significantly. Most of the GM corn in U.S. is used to produce ethanol, which may buffer the market against shocks in demand and supply. Unlike StarLink, MIR162 is accepted in the U.S. but not in China. Hence, the price impact of MIR162 may mainly come from a reduction in U.S. corn exports rather than from domestic consumer reactions. Since China is the third largest importer of U.S. corn and the largest importer of U.S. sorghum, price impacts of MIR162 on the U.S. corn market is an important question.

## **Data and Methods**

### ***Data***

We examine corn and sorghum cash prices from January 3, 1989 to April 1, 2015. The data are average daily processor bids on the Central Illinois and Texas Gulf markets, which are considered the most liquid for corn and sorghum, respectively. The data are obtained from the Agricultural Marketing Service (AMS) USDA and Commodity Research Bureau (CRB).<sup>1</sup>

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<sup>1</sup> We thank Dr. Aaron Smith for providing the data through the StarLink event.

Because AMS only started collecting sorghum daily bids in the Texas Gulf after January 2000, the prices before 2000 are obtained from CRB.

### ***Methods***

The impacts of events on commodity prices are commonly examined by structural break tests (e.g., Carter and Smith, 2007; Jin, Power and Elbakidze, 2008). We employ two structural break tests, the Bai-Perron and the time-varying cointegration method. The Bai-Perron test is the standard test for detecting multiple structural changes. This test provides explicit breakpoint dates. However, this test forces structural change to be sharp. If the mean of a time series shifts smoothly, the test may be inappropriate. Carter and Smith (2007) use the Bai-Perron test to identify structural breaks in the relative prices of corn to sorghum caused by StarLink. In addition, we apply a time-varying cointegration method to complement the Bai-Perron test (see, e.g. Jin, Power and Elbakidze, 2008). This method identifies multiple structural breaks in series that are cointegrated in the long run. The method does not force structural change to be sharp but estimates breakpoints indirectly. Both methods identify changes in a stable long-run relationship.

#### *Bai-Perron Procedure for the Relative Price of Substitutes Method (RPS)*

Carter and Smith (2007) propose the RPS method to identify the price impact of a market event, which avoids specifying supply-demand structural models. The RPS method involves structural break tests to the relative price of two substitutes under the assumption that the event significantly affects only one of the substitutes. In the absence of a market event, relative prices are assumed stable, because the two substitutes are cointegrated. In this context, one can specify a stable relative price prior to an event using,

$$\log(P_{1t}/P_{2t}) = \alpha + \beta'X_t + u_t, \quad (1)$$

where  $P_{1t}/P_{2t}$  is the relative price of corn and sorghum in period  $t$ ,  $u_t$  is a stationary random variable, and  $X_t$  denotes supply and demand shifters. Since we consider a stationary relative price, we exclude  $X_t$ . We then test for shifts in the parameter  $\alpha$  during the event to identify the price impact.

When the number of possible break points is unknown, the problem of identifying structural breaks can be complicated. In this case, if the series is stationary around a small set of discrete breaks in its unconditional mean, one can apply Bai and Perron (1998) test. This test provides both the number and location of the breaks by searching for the maximum F-statistics among all possible break points. In effect the Bai-Perron is sup-F test, which is the maximum value of the Chow (1960) test. We use the Bai-Perron tests for a change in  $\alpha$  in equation (1) and report the significance and timing of the event. However, the Bai-Perron tests forces the parameter shifters to be discrete. In other words, it forces the structural changes to be sharp. If the mean relative price shifts gradually, the Bai-Perron tests generate imprecise estimate of the timing (Enders and Holt, 2012).

### *Time-varying Cointegration*

The time-varying cointegration (TVC) method also identifies structural changes in cointegrated time series but it does not force structural change to be as sharp as the Bai-Perron test. As we can see from Figure 1, the log relative price does not appear to be piecewise stable, which reduces the power of the Bai-Perron test. The TVC method can capture gradual changes in the cointegrating relationship, as long as the two price series are cointegrated over the entire period. Similar to the RPS method, the TVC method can only detect structural breaks caused by an event that affect only one of the price series (or affect the two price series at significantly different

ways). However, the TVC method is unlikely to report as precise break dates as the Bai-Perron method.

TVC methods aim to test for parameter constancies or cointegration instabilities (Juselius, 2006). Cointegration instabilities are defined as switching between rejecting and failing to reject the null hypothesis that at most  $r$  vectors are cointegrated. Here, we employ the Johansen test (or trace test) in a forward recursive manner (Mjelde, Bessler, and Jerko, 2002; Jin, Power, and Elbakidze, 2008). To use the TVC method, prices series are  $I(1)$  and cointegrated in the long-run. Any non-stationary series that are cointegrated may diverge in the short-run. Such a deviation from equilibrium suggests a possible structural break, which is discernible in the Johansen trace test graph. The trace test is commonly used for recursive cointegration test and is expressed as,

$$Trace = -T \sum_{i=r+1}^M \ln (1 - \lambda_i) \quad (2)$$

where  $T$  is the total number of observations,  $\lambda_i$  is the estimated eigenvalues of the sample variance-covariance matrices (see Johansen and Juselius, 1990). Suppose there are  $\Pi$  series of interest. The null hypothesis of the trace test is that the rank of  $\Pi$  is less than or equal to  $r$  cointegrating vectors. If trace test statistic is greater than the critical value, we reject the null hypothesis.

The procedure is divided into several steps. After determining whether the prices are non-stationary and cointegrated, we generate a series of recursive trace tests. To do this, we need to decide appropriate number of observations,  $n$ , within a fixed rolling window time frame. A large number of observations will approximate the long-run cointegrating relationship, but may not detect short-run deviations or structural breaks. We explore the sensitivity of the results to different window sizes. Then, we calculate the first trace test from the first  $n$  observations. Subsequently, we add a new observation and drop the first observation to maintain the number of

observation fixed and recalculate the trace test. This process is continued to the end of the period. Trace statistics are normalized by dividing them by the appropriate critical value. When the null hypothesis is rejected, the normalized trace statistic is greater than one by definition. For two cointegrated series, the normalized trace statistic is equal to the trace statistic divided by the 5% critical value of the null hypothesis that the rank is equal to zero. A normalized trace statistic falling below one signals that a structural shock causes the two series to diverge.

## **Empirical Results**

### ***Summary statistics***

Table 2 presents the summary statistics of corn and sorghum cash prices and the log relative corn prices from January 3, 1989 to April 1, 2015. Table 2 also provides the average prices and the standard deviations for different sub-periods. Generally, the corn and sorghum prices move closely together over time, in accordance with their close substitute relationship. The average cash prices of corn and sorghum were relatively stable until 2000, changing from \$2.38/bu to \$2.54/bu and from \$2.62/bu to \$2.74/bu, respectively. During 2001-2006, the average corn prices declined to \$2.17/bu while the average sorghum prices stayed around \$2.67/bu. After 2006, both of the average corn and sorghum prices rose dramatically to \$4.79/bu and \$5.28/bu, respectively. The corn prices rose more significantly as the log relative price increased from -0.21 to -0.11. The standard deviations of the two cash price series indicate that the corn prices are more volatile.

### ***Relative price of corn and sorghum***

The corn prices are generally lower than the sorghum prices (Figure 1). Recall that corn prices are measured at the farm level in Central Illinois while sorghum prices are port prices. Hence, sorghum prices include transportation costs from farms to the port but corn prices do not. For

the periods identified (Table 2), the corn price was approximately 90 percent of the sorghum price except for 2001-2006 when it dropped to 81 percent.

Figure 1 reinforces our explanation of the price behavior in the summary statistics section and shows some prominent changes in these price series from January 1989 to April 2015. First, the log relative corn to sorghum price peaked in 1996 as corn prices soared. This shock was influenced by a dramatic reduction in 1995/96 corn production. Corn production fell from a record high of 10.1 billion bushels in 1994/95 to about 7 billion bushels in 1995/96 due to the drought in the Midwest (Feed Outlook, USDA). Second, from 2001 to 2005, the log relative price stayed low because corn prices were much lower than sorghum prices. During this period, several GM corn contamination events occurred. Third, from 2006 to 2013, the log relative price rose gradually. With the increasing demand of ethanol, both corn and sorghum prices rose gradually but corn prices increased more. Finally, after 2013, the log relative price dropped sharply as corn prices declined. In 2013, several major events occurred in the corn market, such as record-high corn production, EPA's proposal for reducing ethanol proportion, and MIR162. We provide details in the discussion section.

To apply the RPS method, we show that the log prices are non-stationary and the log relative price is stationary before the shock (i.e. 2000 StarLink shock). We examine the long-run stable relative price before GM contamination incidents by showing that the corn and sorghum prices were cointegrated with a (1, -1) cointegrating vector. The form of the cointegration between corn and sorghum prices is

$$(Pc_t - Ps_t) = \alpha + z_t \quad (3)$$

where  $Pc_t$  denotes the log price of corn,  $Ps_t$  denotes the log price of sorghum and  $z_t$  is a stationary error term. We employ the Augmented Dickey-Fuller (ADF) test to  $(Pc_t - Ps_t)$  and

report the results in Table 3. We test the log prices and the log relative price for the period prior to 2000 and for the entire sample period, shown in Panel A and B. Table 3 Panel A suggests that the log relative price is stationary and therefore that corn prices and sorghum prices were cointegrated prior to 2000. We also utilize commonly used unit root tests for both levels and first differences, including Dickey-Fuller, Phillips-Perron, Zivot-Andrews and KPSS tests. Results are consistent with the ADF test in Table 3.

### ***Structural break tests for stability***

Table 4 presents the Bai-Perron test results for the entire sample period, the period before 8/20/2005, and after 8/20/2005, in Panel A, B, and C. Because the Bai-Perron test may provide imprecise estimates with smooth shifts, we split the entire sample period at the Hurricane Katrina for two reasons.<sup>2</sup> First, the hurricane suspended the delivery of corn from farm to port, which led to the decline in corn prices at farm level and then an increase when the Mississippi waterway was repaired. Second, in 2005 RFS boosted corn use for ethanol production and triggered the expansion of U.S. corn market. Panel A identifies one structural break for the entire sample period that occurred on 06/30/2000. However, since the log relative price behavior is not consistent with the structure of the Bai-Perron test, testing for the entire period (Panel A) may fail to detect structural breaks. Panel B identifies two breaks (7/17/2000 and 03/14/2000) in the first sub-period. Panel C identifies one break (09/25/2013) in the second sub-period.

The results of the Bai-Perron test suggest that StarLink caused a significant structural shock to the corn market. Panel A identifies a potential structural break around July 2000 that emerges strongly in Panel B. The date is identical to Carter and Smith's (2007) finding. Because the first sub-period is very close to Carter and Smith's sample, it is not surprising to find the

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<sup>2</sup> Hurricane Katrina occurred August 29 to August 31, 2005, causing vast damage to the Mississippi waterway.

maximum-F statistic on 7/17/2000. Panel B also identifies a second structural break on 3/14/2002 if we test for two structural breaks versus one break in the first sub-period. However, the magnitude of the second break is much smaller than the first one. In terms of the timing, we conclude that StarLink caused the first structural break around July 2000.

The Bai-Perron test also detects a structural break in September 2013, just prior to the MIR162 event. Examination of Figure 1 shows a pronounced decline in 2013 that is identified as a structural break by the test for the second sub-period (Panel C). The significant structural break was detected in 9/25/2013, which slightly before the MIR162 import ban at the end of November 2013.

The TVC structural break test can be understood with the context of a vector error correction model (VECM) of corn and sorghum prices. The VECM is expressed as,

$$\Delta P c_t = \rho_c \mu_{t-1} + \beta_c(L) \Delta P c_{t-1} + \gamma_c(L) \Delta P s_{t-1} + \varepsilon_{ct} \quad (4)$$

$$\Delta P s_t = \rho_s \mu_{t-1} + \beta_s(L) \Delta P c_{t-1} + \gamma_s(L) \Delta P s_{t-1} + \varepsilon_{st}$$

where  $\beta_c(L)$ ,  $\gamma_c(L)$ ,  $\beta_s(L)$ , and  $\gamma_s(L)$  are polynomials in the lag operators and  $\mu_{t-1} = (P c_t - P s_t - \alpha)$  is the error-correction term as defined in equation (4). The parameters  $\rho_c$  and  $\rho_s$  measure the speed that corn and sorghum prices revert to the long-run common stochastic trends. The greater  $\rho_c$  and  $\rho_s$ , the faster a series reverts to their long-run trend after a shock. Most of the information criteria suggest the optimal lag length to 3. The result of the Johansen test suggests that corn price and sorghum price are cointegrated with rank of 1 from January 3, 1989 to April 1, 2015.

As discussed, change of cointegrating relationships over time can identify the timing of structural breaks. In the long run, the rank of the impact matrix is 1, which means corn and sorghum prices are cointegrated. When a market shock makes the two price series diverge, the



rank of the impact matrix becomes zero. The change of the impact matrix rank can be easily observed at the time point the normalized trace statistic falls below one. We generate the normalized trace tests with 2-, 4- and 8-year observations but focus on the results of the 4-year.<sup>3</sup> We find similar general patterns for these tests but the sensitivity of the normalized time-varying trace statistics varies according to the size of the rolling window. The wider the window, the more stable the cointegrated relationship between corn and sorghum prices. We provide the 4-year results as they allow for deviations from cointegration, which most clearly reflect the GM market events.

Figure 2 plots the time-varying trace test with the 4-year rolling window. Figure 2 shows the normalized trace statistics recursively estimated from the VECM with a restricted constant. Informatively, we observe a downward trend of cointegration from the time-varying cointegration tests, reflecting that corn and sorghum prices are becoming less cointegrated over time, particularly after 1997. This may be related to shifts in the demand and supply of corn and sorghum as well as the substitution relationship between them. The test identifies three breaks relevant to the GM corn contamination events: 11/16/2000, 4/3/2002, and 12/22/2004.<sup>4</sup> The first clear break in the cointegrating vector relevant to contamination events is identified four months after the StarLink data discussed earlier. Here, this break is presumably also associated with StarLink since no other significant events were reported in the U.S. corn or sorghum markets in 2000. The second and third breaks are also relevant to the GM contamination events that occurred between 2002 and 2004. The second break identified on 4/3/2002 is very close to the 3/14/2002 one identified by the Bai-Perron test (see Table 4, Panel B). Figure 2 also shows that corn and sorghum prices were not cointegrated between November 2010 and February 2013.

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<sup>3</sup> The results for 2-year and 8-year observations are available upon request.

<sup>4</sup> Other breaks in the figure because they are not relevant to the GM corn contamination events.

During this period, in 2012, drought damaged portions of major crops in the Midwest, especially corn and soybeans. Sorghum production was relatively less affected, because sorghum is more drought-tolerant than corn. Consequently, the farm price of corn increased proportionally more than the sorghum price, keeping corn and sorghum prices apart. At the end of this period, prices reverted back towards cointegration, but on 3/6/2013 a last sharp drop in corn prices sent the normalized trace statistic below 1 (also see Figure 1 for the decline in corn prices). Apparently, there was no change in this situation near the end of November 2013, the beginning of MIR162. Starting at the end of November 2014, corn and sorghum prices became returning to their long-run relationship that was reached in April 2015.

## **Discussion**

Both the RPS and the TVC methods suggest that the latest prominent downturn in the U.S. corn market started before MIR162. However, multiple changes have occurred in addition to MIR162, which appear to be weakening the relationship between corn and sorghum prices. To assess the MIR162 event more completely, we examine a time-line of daily price movements from September 2013 to April 2015. In September 2013, the log relative corn prices dropped dramatically and then the log relative prices stayed low. The beginning of this downturn is close to the last structural break identified by the Bai-Perron test, and one of the last spikes reflecting cointegration in the TVC method.

We provide Figures 3, 4 and 5 and Table 5 to analyze prices, changes in supply and demand of U.S. corn, and exports for corn and sorghum during this critical period. Figure 3 plots corn and sorghum prices (\$/bu) along with log relative prices from September 2013 to April 2015. Figure 3 indicates major relevant events by vertical lines. Figure 4 illustrates monthly U.S. corn and sorghum exports to China. Figure 5 shows the monthly U.S. exports of corn to its top 5

buyers and buyers with most significant changes during this critical period. Table 5 shows the changes in supply and demand of U.S. corn from the 2011/12 to 2014/15 market year, which assists in the discussion of prices.

Several major events related the U.S. corn and sorghum markets occurred starting in September 2013 to December 2014. First, the relative corn to sorghum prices slumped at the beginning of September 2013. At that time, estimates of high corn production began to emerge as above trend yields became more evident (*Farmdoc Weekly Outlook*, September 9, 2013). On September 12 USDA increased its forecast of the corn production for the 2013/2014 marketing year. In addition, drought reduced sorghum yields, keeping sorghum prices high (USDA Feed outlook, August 2013). High corn production and reduced sorghum yields resulted in low relative prices in September 2013. In October 2013, key changes in the EPA proposal for 2014 started to appear. EPA proposed a reduction in the biofuels mandate, including renewable (ethanol) mandates, under the RFS beginning in calendar year 2014 (*Farmdoc, Weekly Outlook*, October 14, 2013). Note that from September to October 2013, corn exports to China and total of other countries increased sharply while sorghum exports to China increased slightly (Figure 4 and 5). On November 15, EPA officially disclosed the proposal maintaining the downward pressure on corn prices. Only at the end of November 2013 did China reject and cancel U.S. shipments containing MIR162 corn. A zero-tolerance policy almost stops all the U.S. corn exports to China by January 2014 (Figure 4 and 5). Despite this ban, corn prices and relative prices actually increase gradually until mid-May 2014.

In early July 2014, corn prices declined while sorghum prices in response to export demand rose slightly. As a result, the relative corn prices dropped significantly. This sharp decline in corn prices was related to the expectations of a very large U.S. corn harvest in 2014,

which was estimated to exceed the harvest in 2013 (*farmdoc daily*, July 14, 2014). In addition to the large corn harvest news, China detected MIR162 in nearly 1,000 batches of imports from the U.S. DDGS, totaling 415,600 tons, according to a notification from Chinese authorities to the USDA (Sikich AgriBusiness Update, Spring/Summer 2015 edition). The rejection to U.S. DDGS shipment likely reduced the corn prices since DDGS is a corn by-product. On August 12, 2014, USDA expected record-high corn production in 2014, up 1 percent from 2013. At that time, both production and average yield of corn in 2014 were estimated at record highs while the area harvest went down slightly from 2013. Similarly, while U.S. sorghum production in 2014 increased 10% from 2013, China's imports of U.S. sorghum were a record high in August 2014 (Figure 4). Consequently, corn prices declined more than sorghum prices until October 2014. Total supply in the first quarter of 2014/15 (i.e., September-November 2014) marketing year was substantially larger than early marketing years (Table 5). Despite this large production and earlier drop in relative prices, corn prices actually increased from October 2014 through January 2015 as rumors and official announcements of the end of the ban MIR162 emerged. Subsequently, prices became more relatively stable and a long run cointegrating vector re-emerged.

Part of the difficulty in interpreting the relative price ratio during this period is that China and other buyers changed their purchasing patterns on the international market. In August 2013, China begins to import U.S. sorghum considerably before the ban and increases its imports of U.S. sorghum significantly right after it officially banned MIR162 corn (Figure 4). In 2014, U.S. exports of sorghum to China exceed U.S. corn exports to China by 6 million metric tons (i.e. 237 million bushels). China becomes the largest U.S. sorghum importer. Interestingly, Figure 5 illustrates that among other major U.S. corn buyers, such as South Korea, Mexico, and Japan,

increased their corn imports almost immediately after China rejected the shipments containing MIR162, perhaps supporting corn prices. While most of U.S. corn exports to China were rejected, the total U.S. corn exports went up by April 2014 (Figure 5). During the week ending April 17 2014, U.S. corn shipments hit record highs since 1990. More than 1.6 million metric tons of corn was loaded for shipment in the United States (*Reuters*, April 24, 2014). The record high corn exports were likely influenced by somewhat lower prices. Lower U.S. corn prices may have attracted regular buyers and new buyers. An April 2014 Reuters article and the July 2014 U.S. Grains Council article report that buyers in Asia and Middle East bought the shipments rejected by China. In addition to the regular buyers, new U.S. corn buyers, such as Egypt, Morocco and Tunisia, were on track to import a record amount of U.S. corn, even though they usually can buy grain less costly from Ukraine.

## **Conclusion**

This paper investigates multiple GM corn contamination events to examine changes in the market effects of GM corn shocks. Since corn and sorghum are close substitutes, we implemented two different approaches to detect structural breaks caused by GM corn contaminations: (a) the RPS approach proposed by Carter and Smith (2007), which tests the relative prices of two substitutes using the Bai-Perron test and (b) a time-varying cointegration method applied by Jin et al. (2008). Since the stationarity condition of corn and sorghum prices in first differences (and the log relative price) is satisfied, we employed the Bai-Perron test and the time-varying cointegration method. The Bai-Perron test detects multiple structural breaks in a stationary series with no smooth shifts and reports identified structural break point dates. In the presence of smooth shifts in a series, the result of this test is less accurate. In order to detect structural breaks regardless of the presence of smooth shifts, we adopt a time-varying

cointegration method that can detect multiple structural breaks in a stable long-run price relationship. However, the time-varying cointegration method is unlikely to provide clear structural break dates. Therefore, we apply both methods to provide a more complete analysis.

Combining the results of the Bai-Perron test and the time-varying cointegration method, we identified at least three significant structural breaks that occurred near the GM corn contamination events, including StarLink and MIR162. These two events are longer and larger than the other event(s). Another structural break detected in 2002 is near two GM corn contamination events, but is much smaller in magnitude. Using the entire sample, the Bai-Perron test provides strong evidence that StarLink adversely affected corn prices. When we break the sample into two sub-periods to allow for Hurricane Katrina, the Bai-Perron test detects breaks in 2000, 2002 and 2013. The time-varying method also demonstrates sharp breaks in cointegration in 2000, 2002, and 2013, which are near to the GM corn contamination events. With regards to the 2013 MIR162 event, both tests identify a structural break before China rejected U.S. corn shipments. The Bai-Perron test identifies the 2013 break on 9/25/2013. The time-varying cointegration method shows that the two price series became less cointegrated near the middle of 2013.

A detailed time-line investigation revealed that multiple major changes in corn and sorghum markets occurred causing corn prices to decline three months before China rejected MIR162 at the end of November 2013. Therefore, we investigated these two markets to identify and confirm the cause of the last structural break. Two record corn harvests and reductions in ethanol mandates put strong downward pressure on corn prices. In contrast, sorghum experienced droughts and record exports increasing prices and putting added downward pressure on the corn to sorghum price ratio used in the analysis. While China may have had an effect on

price when exited from the U.S. corn market and rejected DDGS shipments, other buyers entered to absorb U.S. exports and support corn prices. Nevertheless, rumors and official announcements that the MIR162 ban would be lifted did appear to modestly stimulate corn prices. Overall, domestic supply and demand factors appear to be the primary drivers of corn prices.

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## **Appendix A. Summary of U.S. GM Corn Cases**

- (1) StarLink, a variety of GM corn approved for animal feed and industrial use, was discovered in taco shells in 2000. Because it contains a type of Bt toxin, Cry9C, a potential human allergen, StarLink was never intended for human consumption. Lacking this knowledge, many farmers failed to keep StarLink separate from other food corn, and thus inadvertently contaminated authorized food corn.
- (2) In September 2002, volunteer<sup>5</sup> maize was found growing in an Iowa soybean field, used in 2001 as a ProdiGene (bacteria-resistant GM product) test site for growing an experimental GM maize used in the production of an ovine vaccine.
- (3) The USDA announced on November 12, 2002, that it had quarantined over 2.7 million dollars of soybeans destined for human consumption at a Nebraska grain elevator after finding ProdiGene's GM maize mixed in with the soybeans. This particular GM maize contains genes for producing an experimental vaccine against an ovine disease, transmissible gastroenteritis virus (TGEV).
- (4) An article in the journal, *Nature*, on March 22, 2005, reported that Syngenta had accidentally produced and distributed several hundred tons of unauthorized GM Bt10 (a kind of bacteria-tolerant product) maize between 2001 and 2004 in the U.S. In addition to being used in field trials in Spain, it was probably exported elsewhere. Although the company reported the violation to U.S. authorities in December 2004, it was not disclosed to the public until three months later.
- (5) After the Syngenta case in 2004, the USDA's Animal and Plant Health Inspection Service (APHIS) alleged that ProdiGene failed to monitor for volunteers associated with a 2004

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<sup>5</sup> Volunteers are plants that grow from seed spilled at harvest from a previous crop.

- GE field test of a corn variety modified for use in medical compounds. APHIS inspectors discovered volunteer corn growing and flowering in an area designated for oats.
- (6) The Union of Concerned Scientists in 2004 reported widespread GM contaminations of as much as 1% in non-GM maize, oilseed rape and soybean seed.
  - (7) In a report published by the Soil Association about organic farming, it asserted that the farmers' crops of organic corn are being tainted by neighbors' GM corn. They confirmed such GM contaminations in the U.S. in 2002, 2003, and 2005.
  - (8) Certain environmental groups harshly criticized the USDA for the illegal testing of GM crops in Hawaii in August 2006. A U.S. district judge decreed that APHIS should have considered whether the plants posed any kind of threat to indigenous endangered species before allowing the experimental trials with GM crops for drug production. Corn and sugar cane crops had been modified as such by ProdiGene, Monsanto, the Hawaii Agriculture Research Center and Garst Seed, between 2001 and 2003 (Reuters, August 15, 2006).
  - (9) GMO contamination was discovered in Fedco (Maine-based organic seeds) corn seeds in the fall of 2007. Fedco had tested its sweet corn seed for GMO contamination for at least seven years prior to the contamination discovery.
  - (10) In December 2013, China refused delivery of 545,000 tons of U.S. corn because it contained an unapproved GM strain, MIR162, mixed with the corn imports.

**Table 1. GM Corn Contamination Events**

<b>Event occurred</b>	<b>News released</b>	<b>Description of the event</b>
2000	09/2000	A protein of StarLink corn found in some taco shells sold in retail.
2002	09/2002	GM corn found growing in soybean field.
2002	11/2002	USDA announced that soybean mixed with GM maize.
2001 - 2004	03/2005	Syngenta distributed unauthorized GM maize.
2004	2004	APHIS <sup>6</sup> claimed ProdiGene GM corn was growing in fallow zone.
2004	2004	Union of Concerned Scientists reported widespread GM contaminations in non-GM corn.
2004	2005	A research of Soil Association reveals the contamination of U.S. organic farmers' corn crops by neighboring fields of GM corn.
2001 - 2003	8/2006	USDA issued permits for GM corn trials to produce drugs.
Autumn 2007	Autumn 2007	GMOs contaminated Fedco corn seeds.
December 2013	December 2013	China discovered MIR162 GM corn in corn imports and thereafter rejected all imports containing MIR162 until December 2014.

Note: The events are chronological by news release.

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<sup>6</sup> APHIS is the Animal and Plant Health Inspection Service.

**Table 2. Summary Statistics, January 3, 1989 – April 1, 2015**

	1989 - 1994		1995 - 2000		2001 - 2006		2007 – 2015	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Corn Price	2.38	0.23	2.54	0.78	2.17	0.37	4.79	1.46
Sorghum Price	2.62	0.20	2.74	0.69	2.67	0.39	5.28	1.26
Log relative price	-0.10	0.04	-0.09	0.08	-0.21	0.07	-0.11	0.13
Observation	1517		1514		1459		1898	

Note: The normal units of corn and sorghum prices are \$/bu and \$/cwt, respectively. Here, we convert the unit of sorghum prices to \$/bu.

**Table 3. Augmented Dickey-Fuller Stationarity Tests**

	Test Statistic	5% Critical Value	Conclusion
Panel A. 1/03/1989 – 12/31/1999			
$P_C$	-1.763	-3.410	Unit Root
$P_S$	-1.857	-3.410	Unit Root
Log relative price	-4.755	-3.410	Stationary
Panel B. 1/03/1989 – 4/01/2015			
$P_C$	-2.453	-3.410	Unit Root
$P_S$	-2.915	-3.410	Unit Root
Log relative price	-4.448	-3.410	Stationary
$\Delta P_C$	-59.24	-3.410	Stationary
$\Delta P_S$	-59.849	-3.410	Stationary

*Note:* The ADF test regressions contained an intercept and one lag. Sample period is Jan 1989-Dec 1999.

$\Delta P_C$  and  $\Delta P_S$  are the first difference of log corn price and log sorghum price, respectively.



**Table 4. Bai-Perron Test for Breaks in the Cointegration Relationship**

Panel A. 1/03/1989 – 4/01/2015				
Test	Statistic	5% Critical Value	Date of Maximal F-Statistic	Conclusion
UDmax	66.13	9.52	–	# breaks $\in \{1,2,3,4,5,6\}$
WDmax	75.98	10.39	–	# breaks $\in \{1,2,3,4,5,6\}$
Sup-F(1 0)	14.73	9.10	06/30/2000	At least one break
Sup-F(2 1)	7.99	10.55	07/17/2000	One break
Panel B. 1/03/1989 – 8/20/2005				
Test	Statistic	5% Critical Value	Date of Maximal F-Statistic	Conclusion
UDmax	169.32	9.52	–	# breaks $\in \{1,2,3,4,5,6\}$
WDmax	194.55	10.39	–	# breaks $\in \{1,2,3,4,5,6\}$
Sup-F(1 0)	133.94	9.10	7/17/2000	At least one break
Sup-F(2 1)	41.02	10.55	03/14/2002	At least two
Sup-F(3 2)	3.47	11.36		Two breaks
Panel C. 8/21/2005 – 4/01/2015				
Test	Statistic	5% Critical Value	Date of Maximal F-Statistic	Conclusion
UDmax	36.00	9.52	-	# breaks $\in \{1,2,3,4,5,6\}$
WDmax	57.30	10.39	-	# breaks $\in \{1,2,3,4,5,6\}$
Sup-F(1 0)	16.47	9.10	09/25/2013	At least one break
Sup-F(3 2)	9.86	10.55	09/18/2013	One break

*Note:* Maximum number of breaks set to six and minimum regime size to 5 % of sample. Robust standard errors with AR(1) prewhitening used for all tests (Bai and Perron, 1998).

Table 5. U.S. Corn Supply and Disappearance, 2011 – 2015 (million bushels)

Marketing year and quarter		Supply	Domestic use	Exports	Total Disappearance
2011/12	Q1 Sep-Nov	13,446	3,393	406	3,799
	Q2 Dec-Feb	9,651	3,183	444	3,627
	Q3 Mar-May	6,034	2,488	398	2,886
	Q4 Jun-Aug	3,159	1,879	291	2,170
	MY Sep-Aug	13,471	10,943	1,539	12,482
2012/13	Q1 Sep-Nov	11,779	3,525	221	3,746
	Q2 Dec-Feb	8,078	2,517	161	2,678
	Q3 Mar-May	5,440	2,488	186	2,674
	Q4 Jun-Aug	2,806	1,822	162	1,985
	MY Sep-Aug	11,904	10,353	730	11,083
2013/14	Q1 Sep-Nov	14,665	3,862	350	4,212
	Q2 Dec-Feb	10,459	3,059	390	3,451
	Q3 Mar-May	7,017	2,529	636	3,165
	Q4 Jun-Aug	3,858	2,081	544	2,626
	MY Sep-Aug	14,686	11,534	1,920	13,454
2014/15	Q1 Sep-Nov	15,452	3,840	401	4,241
	Q2 Dec-Feb	11,217	3,063	404	3,467
	Q3 Mar-May	7,760	2,771	536	3,307
	Q4 Jun-Aug	4,464	2,210	523	2,732
	MY Sep-Aug	15,479	11,883	1,864	13,748

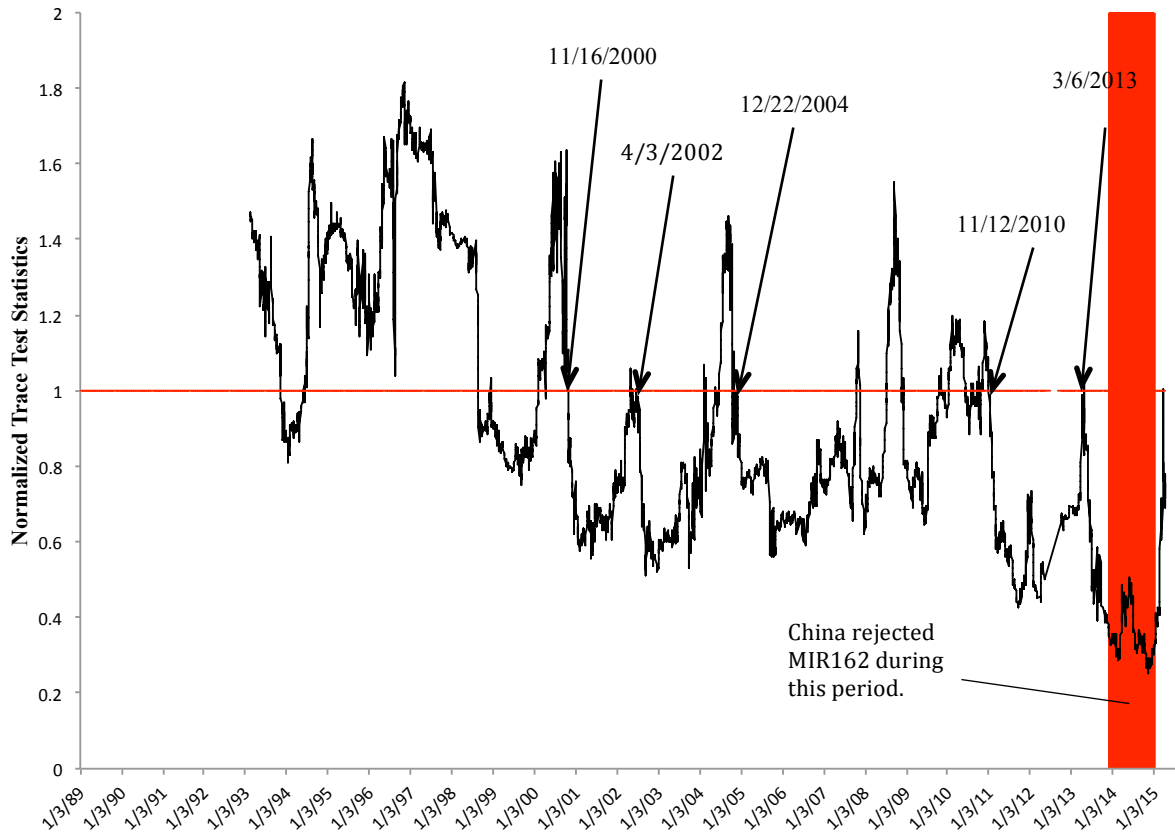
Note: Source: USDA, World Agricultural Supply and Demand Estimates and National Agricultural Statistics Service. Market year supply data are preliminary or projected. Supply= Beginning stocks + Production + Imports. Domestic Use = Fuel ethanol use + Total food, seed, and industrial use + Feed and residual use, where total food, seed, and industrial use includes high-fructose corn syrup (HFCS), glucose and dextrose, starch, seeds, alcohol for beverages and manufacturing and cereals and other products. Total disappearance = Domestic use + Exports.

**Figure 1. Log Corn and Sorghum Prices and the Ratio, January 3, 1989 – April 1, 2015**



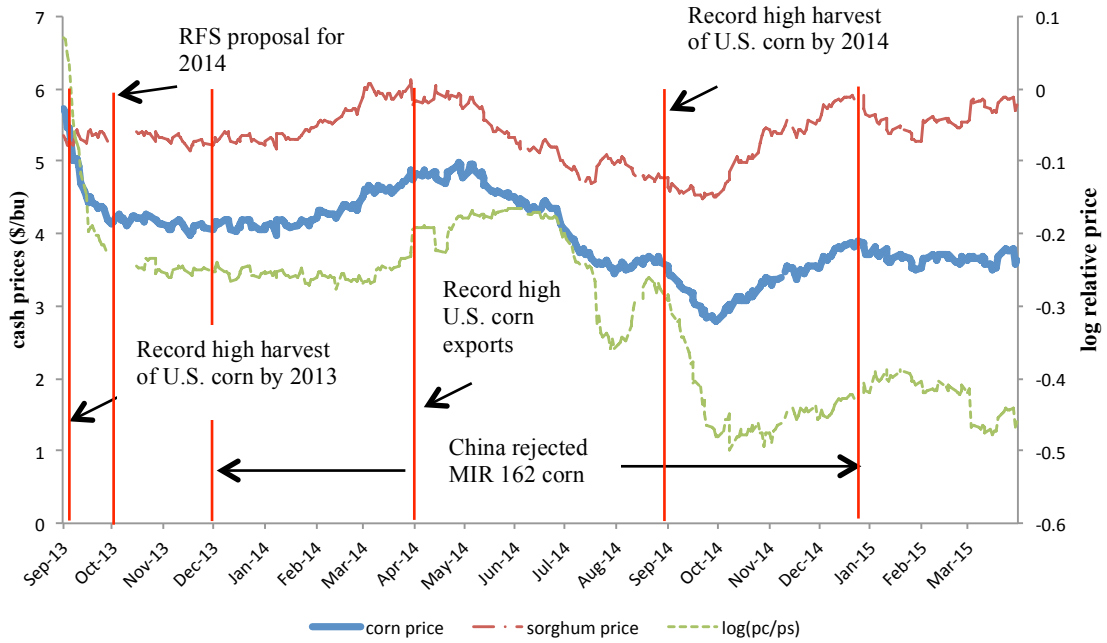
Note: The ratio of log corn and sorghum prices is also called the relative corn price in this paper.

**Figure 2. Time-varying Trace Test, January 3, 1989 – April 1, 2015**

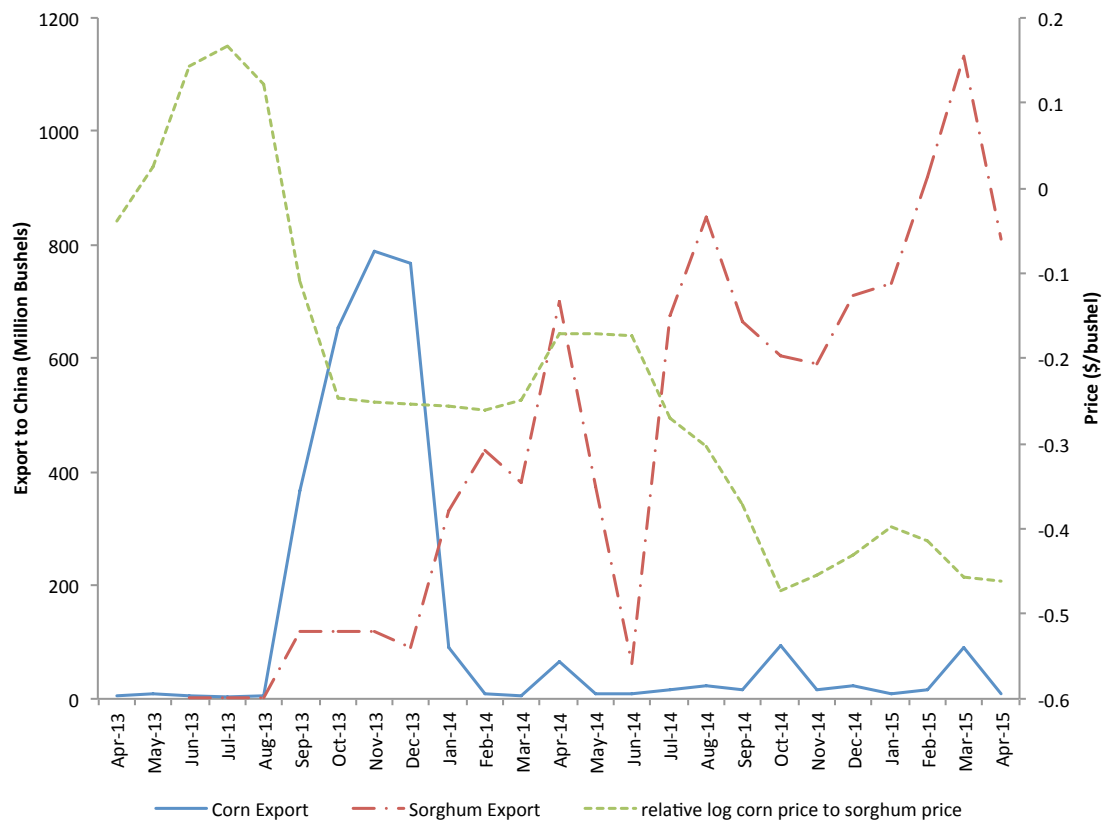


Note: The rolling window for this recursive trace test is 4-year (i.e. 1040 workdays). The null hypothesis is there is less than or equal to zero cointegrating vector. The normalized trace statistic is equal to the trace statistic divided by the 5% critical value. MIR162 is shaded in red, according to China's official announcement dates. We point out three break dates that are close to GM corn contamination events. Other break points identified in this test are not relevant to GM corn contamination.

**Figure 3. Relative Log Prices, September 1, 2013 – April 1, 2015**

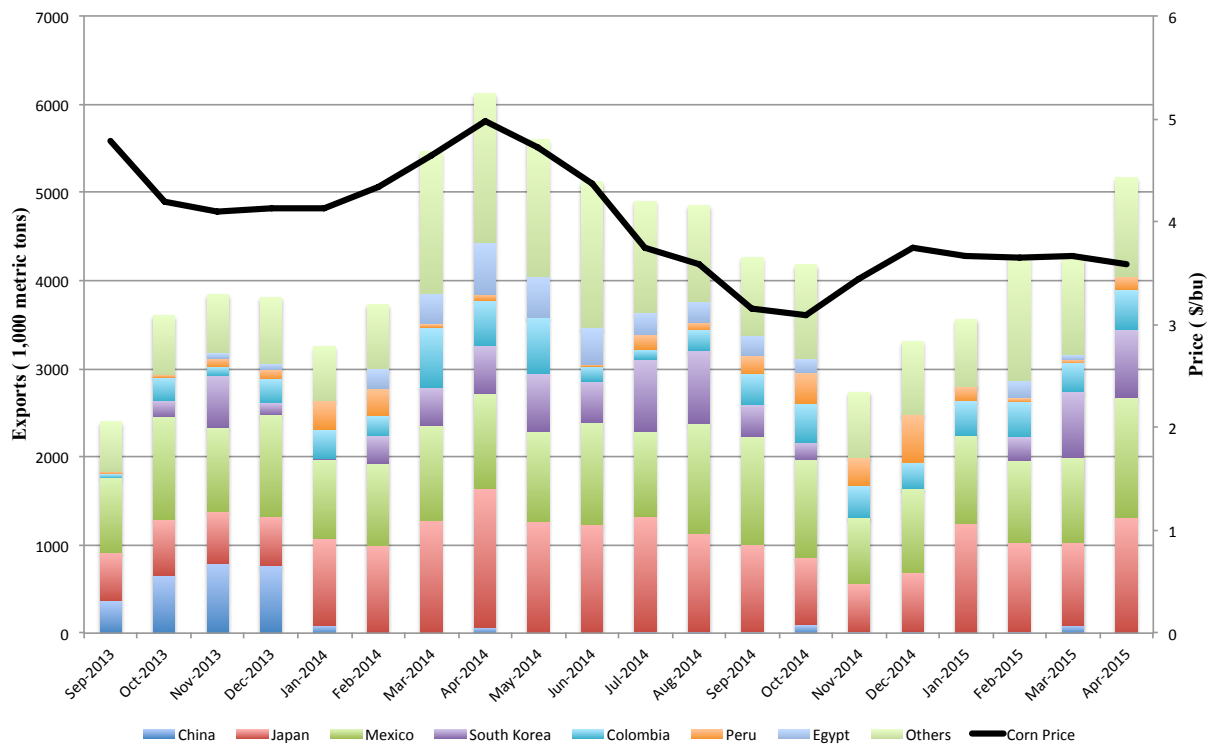


**Figure 4. U.S Exports of Corn and Sorghum to China, April 2013 – April 2015**



Source: Feed Grains Database, ERS, USDA.

**Figure 5. Monthly U.S. Exports of Corn vs. Corn Prices, September 2013 – April 2015**



Source: Feed Grains Database, ERS, USDA.