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

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Abstract

While genetically modified technology has been investigated extensively, few studies have examined the actual price impact of genetically modified grain 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 two primary structural breaks most relevant to the corn contamination events, StarLink and MIR162 events. Our results support the StarLink’s large effect on corn prices found in the literature, but the price effect attributed to MIR162 is less clear. The break in prices near the MIR162 event, which was attributed to China’s rejection of the contaminated corn, emerged three months prior to import ban. The magnitude of the price change was influenced by changes in U.S. corn and sorghum supply, and EPA’s proposed reduction of the ethanol mandate. Expansion of sorghum exports and subsequent increased corn production also likely kept pressure on corn prices. While China’s import ban on MIR162 and DDGSs may have resulted in delayed and cumulative changes in prices, evidence suggests the subsequent downturn in the U.S. corn market was more likely influenced by other domestic supply and demand changes.

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Introduction

Since 1996, genetically modified (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 characteristics, have stimulated their adoption by producers. The adoption of GMOs 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 Asia. 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 U.S. corn producers.

The purpose of this paper is to examine the price impacts of multiple GM corn contamination events in the U.S. markets. Contamination can result from mixing approved and unapproved crops in the market channel and by comingling seeds. GeneWatch UK has identified ten GM corn contamination events. They are listed chronologically in Table 1 (and described in more detail in the Appendix). Most of these events were small in magnitude, received little attention in the press, and we expect them to have had little impact on U.S. corn market. The two primary exceptions are the StarLink and MIR162 events. StarLink corn was developed by Aventis CropScience, a multinational company based in France. This variety was approved only for feed and non-food industrial uses, and not intended for human consumption due to its uncertain health effects. In September 2000, StarLink accounted for 0.5 percent of U.S. total corn production when the Washington Post reported that some taco shells containing a StarLink corn protein were sold in
retail stores. This led to a recall by Kraft Foods, a manufacturer of nearly 300 food products. In
October 2000, a second recall was required as taco shells from Safeway food stores were found to
contain traces of a StarLink protein. Carter and Smith (2007) investigate the price effects of the
StarLink contamination event, finding that U.S. corn prices were reduced by nearly 6.8 percent for
at least a year.

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. In
November 2013, China rejected grain containing MIR162 traits from the United States, and later
officially announced a ban on all MIR162 grains. Starting in November 2013, China rejected more
than 850,000 metric tons of U.S. corn containing the 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. Syngenta 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.

To date, 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 the StarLink contamination event. Using a relative price substitute
(RPS) method and the Bai-Perron test, as identified earlier, they find that StarLink contamination
reduced U.S. corn prices considerably 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 significant but brief effect of GMO contamination in U.S. rice market that persisted for less than a month.

Here, we use two primary methods to assess the impacts of multiple GM contamination events in the U.S. corn market. Both examine the relative price relationship between corn and its close substitute sorghum. First, we follow Carter and Smith (2007) and perform a Bai-Perron structural break test. 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 which could shift the 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. These two procedures complement each other in terms of investigating the multiple-break situations, and consistency in the findings is used to establish the primary events. We also examine time lines, and relate price movements to changes in market variables to strengthen the analysis. We identify two structural breaks relevant to the StarLink and MIR162 contamination events. Our results support the StarLink’s large effect on corn prices, but the effect attributed to MIR162 is less clear. Isolating the effect of the MIR162 event is complicated because other influential market changes occurred near the MIR162 event. Our findings highlight the need for careful assessment of contamination events in agricultural markets.

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).\(^1\) Because AMS only started collecting sorghum daily bids in the Texas Gulf after January 2000, the prices before 2000 are obtained from the CRB.

Methods

The impact 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 can 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

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1 We thank Dr. Aaron Smith for providing the data for the StarLink portion of the sample.
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,

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

(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, $X_t$ can be excluded. 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 can generate an 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 may reduce
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 in significantly different ways). However, the TVC method is unlikely to report as precise break dates as the Bai-Perron method, because it must be estimated without knowledge of the appropriate VECM specification.

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,

\[
Trace = -T \sum_{i=r+1}^{M} ln(1 - \lambda_i)
\]

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. Until 2000, average cash prices of corn and sorghum were relatively stable, changing from $2.38/bu to $2.54/bu and from $2.62/bu to $2.74/bu, respectively. During 2001-2006, average corn prices declined to $2.17/bu while the average sorghum prices stayed near $2.67/bu. After 2006, both of the 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 the description of the price behavior provided by the summary statistics and shows some pronounced changes in the price series. First, the log relative corn to sorghum price peaked in 1996 as corn prices soared. This increase in corn price 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, log relative prices were low since 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 further details in the discussion section.

Prior to performing the analysis, we assess the stationarity of the series. Using the Augmented Dickey-Fuller (ADF) test, it is clear in Table 3 that the log prices are non-stationary and the log relative price is stationary. The log relative test in effect measures the long-run relationship between corn and sorghum prices were cointegrated with a (1, -1) cointegrating vector. Specifically, the form of the cointegration between corn and sorghum prices is

\[(P_{ct} - P_{st}) = \alpha + z_t\]
where $P_{c_t}$ denotes the log price of corn, $P_{s_t}$ denotes the log price of sorghum and $z_t$ is a stationary error term. 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 other unit root tests for both levels and first differences, including Phillips-Perron, Zivot-Andrews and KPSS tests. Results are consistent with the ADF results in Table 3.

**Structural break tests**

Table 4 presents the Bai-Perron results for the entire sample period, the period before 8/20/2005, and after 8/20/2005, in Panel A, B, and C. The sample is split for two reasons. First, Hurricane Katrina hit the U.S in August 2005 suspended the delivery of corn from farm to port, and led to the large decline in corn prices at farm and then an increase when the Mississippi waterway was repaired. 2 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 are consistent with StarLink causing a significant structural shock to the corn market. Panel A identifies a potential structural break near July 2000 which emerges strongly in Panel B. The date of the break in Panel B 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 maximum-F statistic on 7/17/2000. Panel B also identifies a second structural

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2 Hurricane Katrina occurred late August 2005, causing extensive damage to the Mississippi waterway.
break on 3/14/2002 when testing for two structural breaks versus one break in the first sub-period. However, the magnitude of the second break is smaller than the first one, and more importantly occurs six to nine months prior to the news release of the contaminations in 2002 (Table 1). In terms of the timing, we conclude that StarLink caused the first structural break in July 2000.

In Panel C, the Bai-Perron test also detects a structural break in September 2013, near but just prior to the MIR162 event. Examination of Figure 1 also shows a pronounced decline in 2013 that is identified as a structural break. Specifically, the structural break was detected on 9/25/2013, which was 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,

\[
\Delta P_{ct} = \rho_{c} \mu_{t-1} + \beta_{c}(L) \Delta P_{ct-1} + \gamma_{c}(L) \Delta P_{st-1} + \varepsilon_{ct}
\]

\[
\Delta P_{st} = \rho_{s} \mu_{t-1} + \beta_{s}(L) \Delta P_{ct-1} + \gamma_{s}(L) \Delta P_{st-1} + \varepsilon_{st}
\]

where \( \beta_{c}(L), \gamma_{c}(L), \beta_{s}(L), \) and \( \gamma_{s}(L) \) are polynomials in the lag operators and \( \mu_{t-1} = (P_{ct} - P_{st} - \alpha) \) 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. Based on information criteria, the lag structure for VECM suggests the optimal lag length equal 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 when
the normalized trace statistic (Trace statistic/critical value) falls below one. We generate the normalized trace tests using 2-, 4- and 8-year rolling windows for the number of observations but focus on the results of the 4-year.³ We find similar general patterns for these tests with the sensitivity of the normalized time-varying trace statistics changing 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 rolling-window 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 independent shifts in the demand and supply of corn and sorghum as well as a reduction in the degree of substitution between them. The test identifies three breaks relevant to the GM corn contamination events: 11/16/2000, 4/3/2002, and 12/22/2004.⁴ The first clear break in the cointegrating vector relevant to contamination events is identified four months after the StarLink date 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 break 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. During this period, in 2012, drought damaged portions of major corps in the Midwest, especially

³ The 2- and 8-year rolling-window results are available on request.
⁴ Other breaks in the figure are not relevant to the GM corn contamination events.
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 moved toward 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
In evaluating the findings relative to the contaminations, we look for consistency in the test results in the two methods and the timing of the break relative to the occurrence of the contamination event. With regards to timing, more attention is placed on the Bai-Perron results which are not sensitive to the sample and the rolling windows selected. Both the Bai-Perron and the TVC results identify an early break in 2000 which appears to be consistent with the Starlink contamination event. While both methods also identify a break near March 2002, this is considerably prior to the 2002 contamination events (Table 1) which occurred later in the year (October 2002). The 12/22/2004 break identified by the TVC method was not identified by the Bai-Perron test, and the long period of the limited cointegration at this time makes its results somewhat suspect. The final break identified by the Bai-Perron is near 9/25/2013 which is somewhat consistent with long and protracted loss of cointegration identified by the TVC method following the 3/6/2013 break. While somewhat consistent with the Bai-Perron results, both tests suggest that the latest prominent downturn in the U.S. corn market started before MIR162 which began in late November 2013. Figure 2 however suggests that multiple changes, which appear to be weakening the relationship
between corn and sorghum prices, have occurred during the last part of the sample in addition to MIR162.

To assess the MIR162 event more carefully, we examine a time-line of daily price movements, and changes in relevant market indicators for the April 2013-April 2015 period. Figure 3 measures corn and sorghum cash prices ($/bu on the left axis) and log relative prices (on the right axis). Major market events are identified by vertical lines. Figure 4 provides the monthly U.S. corn and sorghum exports to China. Figure 5 shows the monthly U.S. corn exports to its top 5 buyers and provides a measure of their purchases. Table 5 provides quarterly U.S. corn supply and disappearance or use.

Examination of Figure 3 details the trajectory of prices and price relatives. In May, 2013, China destroyed three shipments of GM corn from U.S. (GMWatch, May 22, 2013). However, U.S. corn market did not see changes until mid-July. In mid-July, 2013, corn prices plunged as USDA kept corn production and global stock-to-sue ratio estimates relatively high (Yahoo Finance, August, 16, 2013). In July WASDE report, USDA did not change their projected 2013/14 farm price for corn, which was $4.40 to $5.20 per bushels. In August 12, 2013, USDA forecast a record corn crop and then corn prices crashed and stayed low afterwards (Farmdoc Weekly Outlook, September 3, 2013). In September 2013, the corn price and the log relative prices dropped sharply and then flattened out. In the beginning of September, large corn production estimates were beginning 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 (Figures 4 and 5). On November 15, EPA officially disclosed the proposal maintaining the downward pressure on corn prices. At the end of November 2013, China rejected and canceled U.S. shipments containing MIR162 corn. A zero-tolerance policy nearly stopped all U.S. corn exports to China by January 2014 (Figure 4 and 5). Despite the ban, corn prices and relative prices actually increase gradually through 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 another record U.S. corn harvest in 2014, which was estimated to exceed 2013 production (farmdoc daily, July 14, 2014). In addition to the large corn harvest news, China detected MIR162 in U.S. DDGS imports, totaling 415,600 tons, according to a notification from Chinese authorities to the USDA (Sikich AgriBusiness Update, Spring/Summer 2015 edition). This rejection likely reduced the corn prices since DDGS is a corn by-product. On August 12, 2014, USDA reported 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 reached 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). However, despite large production and
an earlier drop in relative prices, corn prices actually increased from October 2014 to January 2015 (slightly more than sorghum prices). On December 22, 2014, Syngenta confirmed that China officially agreed to accept imports containing MIR162; a decision rumored for several weeks. Following the removal of the ban, prices stabilized 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 in the international market. In August 2013, China began to import U.S. sorghum, and then increased its imports significantly after it officially banned MIR162 (Figure 4). In 2014, U.S. sorghum exports to China exceeded U.S. corn exports by 6 million metric tons (i.e. 237 million bushels), as China became the largest U.S. sorghum importer. Figure 5 illustrates that among other major U.S. corn buyers, including South Korea, Mexico, and Japan, increased their corn imports almost immediately after China rejected shipments containing MIR162, perhaps supporting corn prices. By April 2014, total U.S. corn exports actually increased to a record high since 1990 despite the almost complete GMO ban by China (Figure 5). More than 1.6 million metric tons of corn was loaded for shipment in the United States (Reuters, April 24, 2014). Record high corn exports were likely influenced by lower prices. Lower U.S. corn prices may have attracted both regular buyers and new buyers. Informatively, an April 2014 Reuters article and a 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.

**Concluding Remarks**
According to a National Grain and Feed Association (NGFA)’s analysis, China’s ban on genetically modified (GM) grain cost the U.S. corn, distiller’s dried grains (DDGS) and soy sectors between $1 billion and $2.9 billion in economic losses. This GM grain, MIR162, was 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. This disruption is an example of the consequences that GM contamination events can produce and point to the need to increase our understanding of their market effects.

This paper investigates multiple GM corn contamination events to examine changes in the price effects of GM corn shocks. Since corn and sorghum are close substitutes, we implemented two approaches to detect structural breaks caused by GM corn contaminations: (1) the RPS approach proposed by Carter and Smith (2007), which examines the relative prices of two substitutes using the Bai-Perron test, and (2) a time-varying cointegration method applied by Jin et al. (2008). We use these two tests to detect structural changes in the relative prices and compare these breaks to the reported corn contamination events. The presence of a structural break on dates near events provides statistical evidence of a market moving contamination effect in corn. Interpretation of the statistical findings is supported with time-line analysis of prices and information about the changes in relevant market conditions.

For assessment of the consistency of structural breaks in prices with contamination events, we look for correspondence in the results from the two methods and the timing of the identified break relative to the occurrence of the contamination event. Since the Bai-Perron test provides specific dates, more attention is placed on its results. Combining the results of the Bai-Perron test and the time-varying cointegration method, we identified two significant structural breaks that occurred
near GM corn contamination events—StarLink and MIR162. These two breaks are longer and larger than the other event(s), and occur closely to the reported contamination events. The Bai-Perron test provides strong evidence that StarLink adversely affected corn prices which is consistent with Carter and Smith (2007) who indicated that prices were suppressed by 6.8 percent for more than a year. The other significant break, the 2013 MIR162 event, was identified by both tests to have occurred prior to the late November ban on U.S. corn shipments. The Bai-Perron test identifies the 2013 break on 9/25/2013, while the time-varying cointegration method shows that the two price series became less cointegrated near the middle of 2013.

Detailed time-line investigation of the MIR162 event revealed that multiple major changes in corn and sorghum markets occurred, causing corn prices to decline three months before China’s ban. A record corn harvest 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. While China’s ban on U.S. corn and later rejection of DDGS shipments may have had a delayed cumulative effect on corn price, other buyers entered the market to absorb U.S. exports and support corn prices. Later, a second record corn harvest put added pressure on the market and deepened the decline in price. Rumors in the weeks immediately before the announcement of the ban’s removal appear to have modestly lifted corn prices, but this change was small when compared to the decline in prices that began in September 2013. Following the removal of the ban, prices stabilized.

While contamination events can have large price effects, not all events lead to measureable and significant price change. Identifying the price effects of contamination events in internationally traded agricultural markets is complicated by a variety of factors including the sensitivity of the procedures, changing stochastic supply, and the easily accessible global-nature of markets which
allow users to enter and exit quickly and to substitute lower priced grains. Here, our results support StarLink’s large effect on corn prices, but the large effect attributed to MIR162 is less clear with much of the price decline appearing to be driven by more fundamental supply and demand factors. Research in the future must be aware of the difficulties in isolating contamination-price effects in internationally-traded agricultural commodities, particularly for commodities with a variety of substitutes.

References


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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\(^5\) 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 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.

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\(^5\) Volunteers are plants that grow from seed spilled at harvest from a previous crop.
(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, which was mixed with corn imports.
Table 1. GM Corn Contamination Events

<table>
<thead>
<tr>
<th>Event occurred</th>
<th>News released</th>
<th>Description of the event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>09/2000</td>
<td>A protein of StarLink corn found in some taco shells sold in retail.</td>
</tr>
<tr>
<td>2002</td>
<td>09/2002</td>
<td>GM corn found growing in soybean field.</td>
</tr>
<tr>
<td>2002</td>
<td>11/2002</td>
<td>USDA announced that soybean mixed with GM maize.</td>
</tr>
<tr>
<td>2001 - 2004</td>
<td>03/2005</td>
<td>Syngenta distributed unauthorized GM maize.</td>
</tr>
<tr>
<td>2004</td>
<td>2004</td>
<td>APHIS(^6) claimed ProdiGene GM corn was growing in fallow zone.</td>
</tr>
<tr>
<td>2004</td>
<td>2004</td>
<td>Union of Concerned Scientists reported widespread GM contaminations in non-GM corn.</td>
</tr>
<tr>
<td>2001 - 2003</td>
<td>8/2006</td>
<td>USDA issued permits for GM corn trials to produce drugs.</td>
</tr>
<tr>
<td>Autumn 2007</td>
<td>Autumn 2007</td>
<td>GMOs contaminated Fedco corn seeds.</td>
</tr>
<tr>
<td>December 2013</td>
<td>December 2013</td>
<td>China discovered MIR162 GM corn in corn imports and thereafter rejected all imports containing MIR162 until December 2014.</td>
</tr>
</tbody>
</table>

Note: The events are chronological by news release.

\(^6\) APHIS is the Animal and Plant Health Inspection Service.
Table 2. Summary Statistics, January 3, 1989 – April 1, 2015

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Price</td>
<td>2.38</td>
<td>0.23</td>
<td>2.54</td>
<td>0.78</td>
<td>2.17</td>
<td>0.37</td>
<td>4.79</td>
<td>1.46</td>
</tr>
<tr>
<td>Sorghum Price</td>
<td>2.62</td>
<td>0.20</td>
<td>2.74</td>
<td>0.69</td>
<td>2.67</td>
<td>0.39</td>
<td>5.28</td>
<td>1.26</td>
</tr>
<tr>
<td>Log relative price</td>
<td>-0.10</td>
<td>0.04</td>
<td>-0.09</td>
<td>0.08</td>
<td>-0.21</td>
<td>0.07</td>
<td>-0.11</td>
<td>0.13</td>
</tr>
<tr>
<td>Observation</td>
<td>1517</td>
<td></td>
<td>1514</td>
<td></td>
<td>1459</td>
<td></td>
<td>1898</td>
<td></td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Test</th>
<th>Statistic</th>
<th>5% Critical Value</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel A. 1/03/1989 – 12/31/1999</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC</td>
<td>-1.763</td>
<td>-3.410</td>
<td>Unit Root</td>
</tr>
<tr>
<td>PS</td>
<td>-1.857</td>
<td>-3.410</td>
<td>Unit Root</td>
</tr>
<tr>
<td>Log relative price</td>
<td>-4.755</td>
<td>-3.410</td>
<td>Stationary</td>
</tr>
<tr>
<td>Panel B. 1/03/1989 – 4/01/2015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC</td>
<td>-2.453</td>
<td>-3.410</td>
<td>Unit Root</td>
</tr>
<tr>
<td>PS</td>
<td>-2.915</td>
<td>-3.410</td>
<td>Unit Root</td>
</tr>
<tr>
<td>Log relative price</td>
<td>-4.448</td>
<td>-3.410</td>
<td>Stationary</td>
</tr>
<tr>
<td>ΔPC</td>
<td>-59.24</td>
<td>-3.410</td>
<td>Stationary</td>
</tr>
<tr>
<td>ΔPS</td>
<td>-59.849</td>
<td>-3.410</td>
<td>Stationary</td>
</tr>
</tbody>
</table>

Note: The ADF test regressions contained an intercept and one lag. Sample period is Jan 1989-Dec 1999. ΔPC and ΔPS are the first difference of log corn price and log sorghum price, respectively.
Table 4. Bai-Perron Test for Breaks in the Cointegration Relationship

<table>
<thead>
<tr>
<th>Panel A. 1/03/1989 – 4/01/2015</th>
<th>Test</th>
<th>Statistic</th>
<th>5% Critical Value</th>
<th>Date of Maximal F-Statistic</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDmax</td>
<td>66.13</td>
<td>9.52</td>
<td>–</td>
<td># breaks ∈ {1,2,3,4,5,6}</td>
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</tr>
<tr>
<td>WDmax</td>
<td>75.98</td>
<td>10.39</td>
<td>–</td>
<td># breaks ∈ {1,2,3,4,5,6}</td>
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</tr>
<tr>
<td>Sup-F(1</td>
<td>0)</td>
<td>14.73</td>
<td>9.10</td>
<td>06/30/2000</td>
<td>At least one break</td>
</tr>
<tr>
<td>Sup-F(2</td>
<td>1)</td>
<td>7.99</td>
<td>10.55</td>
<td>07/17/2000</td>
<td>One break</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel B. 1/03/1989 – 8/20/2005</th>
<th>Test</th>
<th>Statistic</th>
<th>5% Critical Value</th>
<th>Date of Maximal F-Statistic</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDmax</td>
<td>169.32</td>
<td>9.52</td>
<td>–</td>
<td># breaks ∈ {1,2,3,4,5,6}</td>
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<tr>
<td>WDmax</td>
<td>194.55</td>
<td>10.39</td>
<td>–</td>
<td># breaks ∈ {1,2,3,4,5,6}</td>
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</tr>
<tr>
<td>Sup-F(1</td>
<td>0)</td>
<td>133.94</td>
<td>9.10</td>
<td>7/17/2000</td>
<td>At least one break</td>
</tr>
<tr>
<td>Sup-F(2</td>
<td>1)</td>
<td>41.02</td>
<td>10.55</td>
<td>03/14/2002</td>
<td>At least two</td>
</tr>
<tr>
<td>Sup-F(3</td>
<td>2)</td>
<td>3.47</td>
<td>11.36</td>
<td></td>
<td>Two breaks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel C. 8/21/2005–4/01/2015</th>
<th>Test</th>
<th>Statistic</th>
<th>5% Critical Value</th>
<th>Date of Maximal F-Statistic</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDmax</td>
<td>36.00</td>
<td>9.52</td>
<td>–</td>
<td># breaks ∈ {1,2,3,4,5,6}</td>
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<tr>
<td>WDmax</td>
<td>57.30</td>
<td>10.39</td>
<td>–</td>
<td># breaks ∈ {1,2,3,4,5,6}</td>
<td></td>
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<tr>
<td>Sup-F(1</td>
<td>0)</td>
<td>16.47</td>
<td>9.10</td>
<td>09/25/2013</td>
<td>At least one break</td>
</tr>
<tr>
<td>Sup-F(3</td>
<td>2)</td>
<td>9.86</td>
<td>10.55</td>
<td>09/18/2013</td>
<td>One break</td>
</tr>
</tbody>
</table>

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

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, April 1, 2013-April 1, 2015

- USDA kept corn production estimate for 2012/13 above the record in 2009/10
- August WASDE report
- RFS proposal for 2014
- Record high U.S. corn exports
- Expectation of another record U.S. corn harvest in 2014; China rejected MIR162 in U.S. DDGS
- China destroyed three shipments of GM corn from US
- China rejected MIR 162 corn
- Record high harvest of U.S. corn by 2014
Figure 4. U.S Corn and Sorghum Exports to China, April 2013-April 2015

Note: Exports reflect the physical movement of grain to China.
Source: Feed Grains Database, ERS, USDA.
Note: Exports reflect the physical movement of grain.
Source: Feed Grains Database, ERS, USDA