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by

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Relative Impact of StarLink and MIR162

Although various topics related to genetically modified (GM) technology have been studied worldwide, few studies have investigated the price impact of genetically modified food events. This paper contributes to the literature by examining the price effects of multiple genetically modified corn contamination events in the U.S. corn market. Using the relative price of substitutes method and the time-varying cointegration, we identify at least three possible structural breaks relevant to the genetically modified corn contamination events. Our empirical results suggest that MIR162 is the largest and longest GM-related break, but notice this break was initially influenced by changes in U.S. corn and sorghum supply, and EPA's proposed reduction of the ethanol mandate. China's rejection of U.S. corn and its substantial imports of U.S sorghum protracted the depression of U.S. corn relative to sorghum until late 2014. Commodity market participants, policy makers and researchers can apply the finding and approach of this paper for anticipating the price impacts of multiple shocks in the commodity markets.

Keywords: corn, sorghum, cointegration, genetically modified organism

Introduction

Since November 2013, China rejected over 887,000 tonnes of U.S. corn containing the unapproved genetically modified (GM) traits, MIR162. [1] According to National Grain and Feed Association (NGFA)'s analysis in April 2014, this trade disruption has 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 created by the biotechnology company, Syngenta. The company has been sued by exporter Cargill, American corn farmers, and others, citing financial damages due to the import ban. As China becomes the third largest U.S. corn importer, MIR162 event could significantly affect the U.S corn market in the short-run. China is also a major buyer of U.S. sorghum, so MIR162 is a good natural experiment to examine the price impacts of exogenous shocks on U.S. corn market relative to sorghum market by applying the relative price of substitutions method proposed by Carter and Smith (2007).

The United States is the world's largest producer and exporter of corn. In the last decade, the average U.S. share of the world corn output and exports was approximately 40 percent and 60 percent, respectively. While 80 percent of the annual U.S. corn crop is for domestic use, about 20 percent is exported to other countries, including Japan, China, Korea and major European countries. The high quality and low prices of U.S. corn drive its global demand consistently high over time. U.S. corn plays an important role not only in the world market but also in the

[1] Tonnes means a metric ton which is equal to 2204.6 pounds.

domestic. Corn accounts for 95 percent of U.S. feed grains. As of 1996 GM varieties of major crops, mainly soybean, corn, cotton, and canola, are commercially available. The desired traits of genetically modified organisms (GMOs) such as time- and cost-efficiency, insect (or bacteria) resistance and herbicide tolerance stimulate the adoption of GM crops.

The adoption of GMOs significantly increases food supply and lowers production costs. The potential benefits of GMOs to producers, consumers, and the environment are tremendous, although controversy on the commercial production and marketing of GM foods has increased, especially in Europe and some Asian countries, such as Japan and China. These countries have cancelled or rejected noticeable quantities of U.S. grain imports in the last decade due to their health concerns of GM crops (Gadsby, 2001, p.5), thus inflicting tremendous losses for U.S. corn producers.

This paper examines how multiple GM corn contamination events affect U.S. corn prices over time. Mixing approved GM crops with unapproved GM crops can lead to such contaminations. Non-GM crops commingling with neighbors' GM varieties of crops through spreading seeds can also lead to such contaminations. To date, at least ten GM corn contamination events have occurred in the U.S. (see Appendix A). The first, and also the most well-known, is the StarLink case. A study conducted by Carter and Smith (2007) shows that the StarLink case reduced U.S. corn prices by about 6.8 percent for at least one year.[2] The price effect of other GM corn contamination events has not been investigated. Moreover, studies about the price effect of other GM crop contaminations are also very limited. Another similar study about the price effect of GM rice contamination shows a significantly adverse but brief effect on the U.S. rice market (Li et al., 2010).

Unlike a one-event study, this paper utilized two different methods to assess the impacts of multiple GM corn contamination events in the U.S. corn market. We employed the Bai-Perron test regarding Carter and Smith's (2007) StarLink study. However, findings of a one-event study may not apply to subsequent events because factors change over the long run. Therefore, we utilize a more recent time series analysis method, the time-varying cointegration, to overcome the limitations of the Bai-Perron test. Jin, Power and Elbakidze (2008) use this new method to assess the impact of multiple Bovine Spongiform Encephalopathy (BSE) events on six series of live cattle future prices, assuming these six price series are cointegrated in the long run. Their result of the time-varying cointegration test indicates that these six series become less cointegrated at the outbreak of BSE events.

This paper identifies at least three structural breaks relevant to GM corn contamination events, including StarLink and MIR162. Result of the time-varying cointegration test shows that the last

[2] StarLink corn was approved for animal feed and non-food industrial uses but not for human consumption. In 2000, StarLink corn entered the human food supply when commingled with non-StarLink corn.

structural break (i.e. during MIR162 period) is the largest and longest. However, several influential events coincided MIR162 from September 2013 to late 2014, which complicated the causality of the last structural break. Therefore, we further observe the U.S. corn and sorghum markets from 2013 to 2014. Combining our testing results and observation, we conclude that the last structural break was initially influenced by changes in U.S. corn and sorghum supply. China's rejection of U.S. corn and its substantial imports of U.S sorghum protracted the depression of U.S. corn relative to sorghum until late 2014.

As the last GM corn contamination event is relevant to the trade policy of China, we discuss the price support policy and changes in U.S. exports of corn and sorghum to China in this paper. MIR162 is different from StarLink in several aspects. First, this GM variety is accepted by the U.S. but not China, so the price impact is mainly from the reduction in exports other than changes in domestic consumption. Second, MIR162 does not only affect the U.S. corn market but also U.S. sorghum markets because China dramatically increased imports of sorghum to resolve their demand for feed. Third, China rejected MIR162 not only for the health concern of GMOs but also for protecting their domestic farmers and their excessive stock of grains.

Background

Corn production and its various uses is an important component of U.S. agriculture. According to Feed Yearbook (U.S. Department of Agriculture, ERS, 2013), annual production of corn is about 11 billion bushels, generating more than $60 billion in revenue for farmers at the end of 2013. On average, approximately 50 percent of the annual U.S. corn supply is for animal feed, and about 12 percent is for domestic food consumption. Exports have decreased from about 20 percent to 15 percent, as explained by the expansion of non-food industrial use (mainly for ethanol production), a declining demand of foreign countries and limited capacity of corn production.

In recent years, U.S. corn production as well as many other grains and fibers have shifted to GM varieties. Fifteen years after the adoption of first-generation GM crop varieties by U.S. farmers, the crop varieties now account for about 90 percent of the planted acres of corn, cotton and soybeans (USDA, National Agricultural Statistics Services, 2014). Although GMO benefits stimulate the adoption of biotechnology, questions about potential risks of GMOs remain.

U.S. Corn Contamination Events

The ten GM corn contamination events are listed chronologically by the news releases of these events in Table 1. The StarLink event is not only the first but also the most famous one. 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 sold in retail stores contained a StarLink corn protein, leading to the precautionary recall by the manufacturer of nearly 300 food products, including more than 70 types of corn chips, 80 kinds of taco shells, and nearly 100 restaurant 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 mixed with food corn though it is possible through storage or transportation. Isolating and preventing unwanted commingled crops was difficult in the existing grain marketing system.

China has enforced a zero-tolerance policy on MIR162 traits in U.S. corn imports since 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) declared 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. The enforcement is comprehensive and in-depth as it includes testing, delays in vessel discharge, and deferrals, diversion and rejections of cargoes.

In the aftermath of the enforcement, China's feed grain import market has almost completely banned U.S. corn. 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 until 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 U.S. corn were shipped to China as of April 22, 2014. In order to replenish the shortage of U.S. corn imports, China increased imports of U.S. grain sorghum, a substitute of corn, and acquired corn from other corn exporters.[3]

On December 22, 2014, Syngenta confirmed that China has finally agreed to accept imports containing MIR162 after the decision had been rumored for weeks. The GM variety has been accepted by major world importers, except China where Syngenta has been applied for approval for almost five years. U.S corn prices have been increasing since October 2014 when the rumor of the approval started. The central Illinois corn price closed at \$2.79/bu on October 1st, 2014 and then peaked at \$3.86/bu on December 22nd, 2014 when Syngenta confirmed the approval.

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 polices during the decade after China joined the

[3] Although China's trade disruption has almost shut out U.S. corn imports, U.S. sorghum imports have increased. This negative correlation fits our research design (i.e. the cointegration methods that we will discuss later).

World Trade Organization (WTO). Several years ago, China's authorities began to support farmers by means of price supports since the former subsidy programs cannot offset the impact of increasing production cost (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 dramatically. China's authorities raised support prices of corn as usual which result 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 to 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*). According to these considerable changes in U.S exports of corn and sorghum, we expect that MIR162 has a significant impact on U.S. corn prices relative to sorghum prices.

Other GM corn contamination events had much less media coverage than StarLink and MIR162. Thus, we might expect the impacts of these events on the U.S. corn market to be weaker. Besides StarLink, GeneWatch UK discovered other eight GM corn contamination events from public news or reports. These eight events are about approved crops 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 will not be discussed in detail.

Among all the ten events, 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 actual 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 the relative price of a 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 for both 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.

Although MIR162 is another GM-related event like StarLink, market reactions to GM corn containment may vary due to the changes in market opportunities and technologies of U.S. corn market. Since 2005, The Renewable Fuel Standard (RFS) has boosted demand for ethanol continuously 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 by U.S. but not China, the price impact of MIR162 mainly comes from the cut in U.S. corn exports other than from domestic consumers' scares of GMO. However, as China has become the third largest importer of U.S. corn and the largest importer of U.S. sorghum, the price impact of MIR162 on the U.S. corn market is an important question needs to be investigated.

We hypothesize that information about GM corn contamination adversely affects corn prices. New negative information on food health concerns adversely affects the prices of that commodity (Fox, Hayes and Shogren, 2002; Brown, Deborah and Schrader, 1990). In addition, non-food industrial use of corn has risen dramatically, so there is a reduced risk of commingling unapproved GM varieties with human food. Therefore, we expect that declining scare of GMO and increasing non-food industrial use of corn reduce the impact of GM corn contamination events on corn prices over time. On the other hand, we expect that the growing importance of China to the U.S. agricultural trade raise the impact of MIR162 on corn prices. This paper aims to these two competing hypotheses.

Data and Methods

Data

To identify the effect of scares, we use daily bid prices of corn and sorghum from January 3th, 1989 to April 1st, 2015. Consistent with previous literature, corn prices and sorghum prices are average daily processor bids on the Central Illinois and Texas Gulf markets, respectively. These two spot markets are considered the most liquid for corn and sorghum, respectively. The data source of corn prices is the Agricultural Marketing Service (AMS), USDA. Since the USDA did not document sorghum prices in the Texas Gulf before January 2000, the prices before 2000 are from the Commodity Research Bureau (CRB).[4]

Methods

Tests for structural breaks are commonly used to identify the effects of events on commodity prices (for example, Carter and Smith, 2007; Jin, Power and Elbakidze, 2008). Bai-Perron test is the standard test for detecting multiple structural breaks. Time-varying cointegration method is an alternative way to identify multiple structural breaks for a multiple series of interests. Carter and Smith (2007) use the Bai-Perron test to identify structural breaks in a series of relative prices

[4] CRB charges for each data package. We would like to thank Dr. Aaron Smith (at the University of California, Davis) for providing the data. We checked the data and confirmed that the prices are the same in CRB and AMS, USDA.

caused by StarLink. Because this paper adopts Carter and Smith's (2007) strategy of RPS, the Bai-Perron test is performed. Moreover, this paper provides results of time-varying cointegration tests as an alternative approach, used by Jin, Power and Elbakidze (2008) to identify the multiple structural breaks of six series of livestock future prices in their BSE study. Both methods examine the price impacts of market events by identifying changes in a stable long-run relationship of series of interest.

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

The RPS method requires the relative price relationship of two series stable prior to the event. The formula is

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

where u_t is a stationary random variable and X_t denotes supply and demand shifters. For a stationary relative price, I can exclude the X_t variables like Carter and Smith (2007). Testing for a shift in the parameter α during the event can indicate the significance of the price impact.[5]

There are several ways to test for parameter shifts, or structural breaks. If there is one known breakpoint, the F-test-based Chow test (1960) is commonly applied. When the break date is unknown, the usual F-statistic makes the statistical inference more difficult because of the nonstandard distribution of F-statistics (Andrews, Lee and Ploberger, 1996). The problem becomes more complicated when the number of possible break points is unknown. Bai and Perron (1998) propose a testing strategy that provides both the number and location of the breaks by finding the maximum F-statistics among all possible break points. Therefore, the Bai-Perron is sup-F test, which is the maximum value of the Chow (1960) test. For stationary data, the Bai-Perron tests for a change in α in equation (1) when there are no X_t variables. Under the RPS method, the Bai-Perron tests report the significance and timing of the event.

Time-varying Cointegration

Time-varying cointegration method does not force structural change to be as sharp as Bai-Perron test does. Enders and Holt (2011) pointed out that Bai-Perron procedure could be problematic if there are smooth shifts in the series. The relative prices of corn to sorghum seem to move upward after 2005 (Figure 1). The provided time-varying cointegration captures both sharp and smooth changes in the two series.

Juselius (2006) introduces a procedure to check the structural break based on cointegration instabilities, switching between rejecting and failing to reject the null hypothesis of at most r cointegrated vectors, suggesting possible structural breaks. The Johansen cointegration approach

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[5] Theoretically, a change in preference or relative technology could change the coefficient β as well which results in a non-stationary price impact. The price impact would be a function of X_t. Following Carter and Smith's (2007) approach, we only focus on the case of a constant price impact though the RPS method applies to such cases.

provides two sequential tests, the trace and the maximum eigenvalue tests (Johansen and Juselius, 1990). These are two likelihood estimators for confidence interval (CI) rank. To test for cointegration, a trace test is usually used. The trace test statistic is expressed as

$$Trace = -T \sum_{i=r+1}^{M} ln\,(1 - \lambda_i) \qquad (3)$$

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

Time-varying cointegration methods employ the trace test in a recursive manner to examine whether the nature of the long-run relationships varies over time (Mjelde, Bessler, and Jerko, 2002). Producing recursive trace tests requires a large number of total observations because trace tests are calculated for a rolling time frame with a fixed and statistically sufficient large window length, n. That is, the first trace test is calculated from the first to the nth observation. Then, trace tests are recursively calculated from 2 to the (n+1) th observation, 3 to the (n+2) th observation, 4 to the (n+3) th observation, etc. Dividing the Johansen trace test statistic by an appropriate critical value, we can get normalized trace statistics. When trace statistics exceed the critical value, the normalized trace statistic is greater than one by definition. By implementing this time-varying cointegration method, I can examine whether the nature of the long-run relationships varies over time.

Empirical Results

Summary statistics

Summary statistics presented in Table 2 indicate that corn and sorghum prices are very close over time and that both rose dramatically after 2006. Log relative price is the log of corn prices minus the log of sorghum prices. Table 2 reveals that log relative prices were stable before 2000 but have been rising since.

Relative price of corn and sorghum

Figure 1 plots the log relative prices of corn and sorghum from 1989 to 2015. Corn prices are generally less than sorghum prices as the log relative prices are generally less than zero. Recall that corn prices are measured at the farm level in Central Illinois while sorghum prices are port prices. Defined another way, corn price is port price less transport costs. Traditionally, grain sorghum price was 95 percent of corn price because grain sorghum has roughly 95 percent of the nutritional value of corn in the feed industry (Schnepf, 2006). As Martinez-Mejia and Malaga (2009) note, the price relationship of corn and sorghum appears to be changing (with the sorghum price approaching 100 percent of the corn price) more recently because they argue sorghum is also being used for ethanol production. Therefore, if the prices were equal, one would expect the corn price to be less than the sorghum price as it is measured at the farm level in Central Illinois.

Particularly, Figure 1 illustrates that the average log difference between corn prices and sorghum prices was very stable before 2001, reflecting that corn and sorghum prices move closely throughout time. It supports the idea that these two commodities are close substitutes, which meets the assumption of the RPS method. According to Feed Outlook provided by the USDA, drought in the Midwest perhaps significantly affected crop production as corn production fell from a record high of 10.1 billion bushels in 1994/95 to about 7 billion bushels in 1995/96. Corn prices were much lower than sorghum prices from 2001 to 2005 and after 2013, even though we consider the corn prices in Central Illinois generally slightly lower than sorghum prices in the Gulf. GM contamination events occurred during these periods. The latest and largest jump occurred in December 2013 when China rejected a large amount of U.S. corn due to the MIR161 commingling.

We demonstrate the long-run stable relative price before GM contamination incidents by showing that the absolute corn and sorghum prices were cointegrated with a (1, -1) cointegrating vector. Therefore, we show the log prices as non-stationary but the log relative price is stationary so that the form of the cointegration between corn and sorghum prices can be

$$(Pc_t - Ps_t) = \alpha + z_t \tag{4}$$

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 test to $(Pc_t - Ps_t)$ and report the results in Table 3. The test suggests that the log relative price is stationary and therefore that corn prices and sorghum prices were cointegrated prior to 2000. Thus, we can apply the test of Bai-Perron test to determine whether the relative price remained stable throughout the entire sample period. In addition, we utilize commonly used unit root tests for both levels and first differences, including Dickey-Fuller, Phillips-Perron, Zivot-Andrews and KPSS tests, to examine the stationarity of the two price series for the entire sample period. Results of all these tests show that corn and sorghum prices are non-stationary in levels but stationary in first differences. Hence, all the results of the unit root tests enable us to apply an error correction model to test the cointegration of the two prices.

Structural break test for stability

The Bai-Perron test is used to examine the stability of relative price through the period containing the ten GM corn contamination incidents. We test for a break in the parameter α in equation (4) using Bai-Perron testing procedure. First, we test for structural breaks over the entire sample period and report the results of this test in panel A of Table 4. Second, we divide the entire sample period into two, with the occurrence of Hurricane Katrina.[6] The hurricane suspended the delivery of corn from farm to port, which led to the slump of corn prices at farm level. In addition to Hurricane Karina, RFS boosted the corn use for ethanol production and therefore triggered the exposure of U.S. corn market since 2005. Since the Bai-Perron test assumes series do not shifts in the long run, we divide the entire sample period into two sub-periods to account for these significant changes in U.S. corn market. The results before and after Hurricane Katrina are presented in panels B and C of Table 4, respectively. Panel A suggests one structural break for the entire sample period. Panel B suggests two and panel C suggests one break in the first and the second sub-period, respectively.

The results of the Bai-Perron test prior to the Katrina period are very similar to the findings of Carter and Smith (2007) as the sample of period 1 is very close to their sample. The date with the maximum F-statistic in Panel B is July 17, 2000, which is identical to that of Carter and Smith (2007). Therefore, the first break can be interpreted as a consequence of StarLink. Panel B further confirms StarLink caused a significant structural break. Panel C indicates that there is a possible structural break in September 2013, which is close to but slightly earlier than when the import ban was announced. Because USDA's forecast of 2013/14 marketing year and proposal of RFS were released close to this breakpoint, we further investigate the U.S. corn and sorghum market for both 2013 and 2014.

In addition to the Bai-Perron test, we employ a vector error correction model (VECM) of corn and sorghum prices to test for structural changes. The VECM is expressed as:

$$\begin{aligned} \Delta Pc_t &= \rho_c \mu_{t-1} + \beta_c(\mathrm{L})\Delta Pc_{t-1} + \gamma_c(\mathrm{L})\Delta Ps_{t-1} + \varepsilon_{ct} \\ \Delta Ps_t &= \rho_s \mu_{t-1} + \beta_s(\mathrm{L})\Delta Pc_{t-1} + \gamma_s(\mathrm{L})\Delta Ps_{t-1} + \varepsilon_{st} \end{aligned} \tag{5}$$

where $\beta_c(\mathrm{L})$, $\gamma_c(\mathrm{L})$, $\beta_s(\mathrm{L})$, and $\gamma_s(\mathrm{L})$ are polynomials in the lag operators and $\mu_{t-1} = Pc_t - Ps_t - \alpha$ is the error-correction term as defined in equation (4). The parameter ρ_c and $\rho_s$measure the speed of corn and sorghum prices reverting to the long-run trend. The larger the ρ_c and ρ_s, the faster the series revert to their long-run trends after a shock.

According to the information criteria, the optimal lag length is 3 for the entire sample period. The result of the Johansen test shows that two price series are cointegrated with rank of 1. The results of cointegration tests for all deterministic structures suggest that corn price and sorghum price are cointegrated with rank of 1.

As discussed in the previous section, change of cointegrating relationships over time can identify the timing of structural breaks. Normalized trace tests clearly show the movement of the cointegrating relationships between corn and sorghum prices. If the rank of the impact matrix is

[6] Hurricane Katrina occurred August 29 with other related storms to August 31, 2005, causing vast damage in various degrees from central Mississippi to Pennsylvania.

1, corn and sorghum prices are cointegrated. If the rank of the impact matrix is zero, then the two series are not cointegrated and a possible break occurs. The idea of the normalized trace test for this model is to find whether the normalized trace statistic is significantly below 1. To check robustness, we tried the normalized trace tests with 2-, 4- and 8-year observations.[7] We observe similar trends among these tests. We find that the volatility or sensitivity of the normalized trace tests depends on the width of the rolling window; the wider the window, the less volatile or less sensitive the test will be; although the significance of the break points can vary, the timing of the breaks does not change. Moreover, we think the 4-year window width is more appropriate for this study as including too many or too few observations may provide inaccurate results.

Figure 2 plots the test with the 4-year window, indicating that corn and sorghum prices are not cointegrated from 2000 to 2001, late 2002, 2012 and late 2013. Recall in Table 1, the possible structural changes in the first two periods and the last may be attributed to the GM contaminations. However, there is no relevant GM contamination incident disclosed in 2012. The drought in 2012 may be considered the reason for the disappearance of the cointegrating relationship. Sorghum is relatively more drought tolerant than corn. The 2012 drought in the U.S. greatly damaged portions of major corps in the Midwest, especially corn and soybean, while sorghum production was relatively less affected. Consequently, the farm price of corn increased proportionally more than the sorghum price, resulting in the disappearance of the cointegration. Additionally, we perceive an downward trend of cointegration from the time-varying cointegration tests, reflecting that corn and sorghum prices tend to become less cointegrated over time, especially for the period after 1997.

Discussion

In this section, we make a closer observation of the daily price movement around the last structural break identified by the time-varying cointegration methods in order to confirm whether the disappearance of the cointegration between corn and sorghum prices was caused by the MIR162. We find that the break was not initiated by the MIR 162 but by the supply and demand factors. Figure 3 plots corn and sorghum prices as well as log relative prices from April 2013 to April 2015. During this period, major events related the U.S. corn and sorghum markets were highlighted by red vertical lines in Figure 3. Noticeably, relative corn prices dropped sharply close to the beginning of September 2013 and then stayed low. There are several relevant events occurred close to September 2013. First, in early September 2013, trade estimated high corn production after the corn yield had been below the trend value for three years (*Farmdoc Weekly Outlook, September 9, 2013*). Second, on September 12th, 2013, USDA increased its forecast of the corn production for the 2013/2014 marketing year. Meanwhile, drought reduced sorghum yields, which kept sorghum prices high (USDA Feed outlook, August 2013). U.S. experienced

[7] The results for 2-year and 8-year observations are available upon request.

record high harvest of corn in 2014, which coincided with MIR162. Under these circumstances, relative corn prices fell again in September 2014 and reached the bottom in October 2014. Undoubtedly, high crop of corn in 2014 reduced U.S. corn prices but it is also possible that MIR162 has protracted impacts on U.S. corn market. Besides the gloomy corn sales to China, China leaped to the largest U.S. sorghum importer in 2014. U.S. exports of sorghum to China soared to more than 4 mmt in 2014 exceeding the exports of corn (Figure 4). China's grand entrance into the U.S. sorghum market coincided with MIR162, further reduced U.S. corn prices relative to sorghum prices in 2013 and 2014.

Besides the health concern of GMO, China rejected MIR162 perhaps due to their high stockpile of corn (Gale, Henson and Jewison, 2015). China's imports of grain (including corn) accelerated every year after it joined WTO. In order to support farmers, Chinese authorities provide price support to farmers and keep increasing support prices every year. During 2014, in order to prevent prices from falling, Chinese authorities reported purchasing 125 mmt of domestic grain – about 20 percent of that year's harvest. In early 2015, Chinese official claimed that reserves of corn, wheat, and rice exceeded 50 percent of domestic annual consumption. This volume far exceeded storage capacity. However, China's overall demand of grain suddenly slowed down during 2013 and 2014 while China experienced record high harvest of corn in 2014. Increasing imports, decreasing demand growth, and record harvest of grain jointly resulted in extremely high reserves. Rejecting U.S. corn imports containing MIR162 allows Chinese market to consume their inventory during the ban period. Nevertheless, Chinese grain buyers or livestock companies complained high domestic feed prices though they have increased their imports of sorghum as a substitute to corn. Since China's rapidly growing livestock sector has stimulated a growing demand for feed and forage, the import ban of MIR162 cannot last for a long time. Around October 2014, the rumor that China would accept MIR162 was released and relative corn prices started to rise. On December 22, 2014, Syngenta confirmed this decision.

In addition to the news on the supply side, the news on the demand side may have had impact on the corn market. EPA disclosed its proposal for 2014 on November 15th 2013. However, the key changes in the proposal that reduce the magnitude of biofuels mandates, including renewable (ethanol) mandates, under the RFS beginning in calendar year 2014, were leaked in October 2013 (*Farmdoc, Weekly Outlook, October 14, 2013*). Therefore, we can conclude that the news of reducing ethanol use under the RFS and the MIR162 kept the corn prices depressed.

Conclusion

This paper investigated multiple GM corn contamination events as natural experiments to examine changes in the market effects of GM corn shocks. Assuming corn and sorghum are close substitutes, we implemented two different approaches to detect the structural break caused by GM corn contaminations: (a) the RPS and (b) the time-varying cointegration method. Because the stationarity condition of corn and sorghum prices in first differences (or the log relative price) is satisfied, we employed the Bai-Perron test and the time-varying cointegration method to detect multiple structural breaks in a stable long-run price relationship.

Combining the results of the Bai-Perron test and the time-varying cointegration method, we identified at least three significant and clear structural breaks related to the GM corn contamination events. Among the multiple structural breaks identified by these two procedures, two of them occurred near StarLink and MIR16, respectively. The Bai-Perron test under the RPS approach provided strong evidence that StarLink adversely affected corn prices. Normalized trace statistics of the time-varying cointegration method demonstrate that the breaks, late 2000, late 2002 and late 2013, are close to the subsequent GM corn contamination events. Note that multiple GM contamination events were reported near the second breakpoint. Our empirical results suggest that MIR162 is the largest and longest GM-related break, but notice this break was initially influenced by changes in U.S. corn and sorghum supply, and EPA's proposed reduction of the ethanol mandate. Since MIR162 was coincided with several other events, we make a closer observation on the U.S. corn market during 2013 and 2014. The dramatically increased corn supply made great impact on the U.S. corn market while the changes on RFS for 2014, cut in corn exports and China's grand entrance to U.S. sorghum market extended the depression of corn prices relative to sorghum prices.

The finding is subject to the identification of structural breaks during the sample period. As we found only three structural breaks occurred close to GM corn contaminations and then inspected the magnitude and persistence of StarLink and MIR162, future research on subsequent events is warranted to enhance the robustness of this empirical study. Since this paper incorporated two approaches, future research that updates the econometric techniques is conducive to the studies examining multiple shocks in a commodity market. Since multiple events occurred in the U.S. corn market during MIR162 period, examining the magnitude and persistent of each event is complicate. Clearly, much work remains for future research.

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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[8] 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 worth 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.

(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

[8] Volunteers are plants that grow from seed spilled at harvest from a previous crop.

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. To its credit, Fedco had tested its sweet corn seed for GMO contamination for at least seven years prior to the contamination discovery.

(10) China refused delivery of 545,000 tons of U.S. corn in December 2013 because it contained an unapproved GM strain, MIR162, mixed in with the corn imports.

Table 1. GM Corn Contamination Events

Event occurred	News released	Description of the event
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[9] 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.

[9] 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[10]	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	

[10] The default units of corn and sorghum prices are \$/bu and \$/cwt, respectively. Using the generally accepted conversion formula, we can get \$1/cwt=56/100 \$/bu. Here, we convert the unit of sorghum prices to \$/bu.

Table 3. Pre-event Stationarity Test, 1989 – 1999

	Test Statistic	5% Critical Value	Conclusion
Augmented Dickey-Fuller Tests			
P_C	-1.40	-3.41	Unit Root
P_S	-1.77	-3.41	Unit Root
Log relative price	-6.10	-3.41	Stationary

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

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

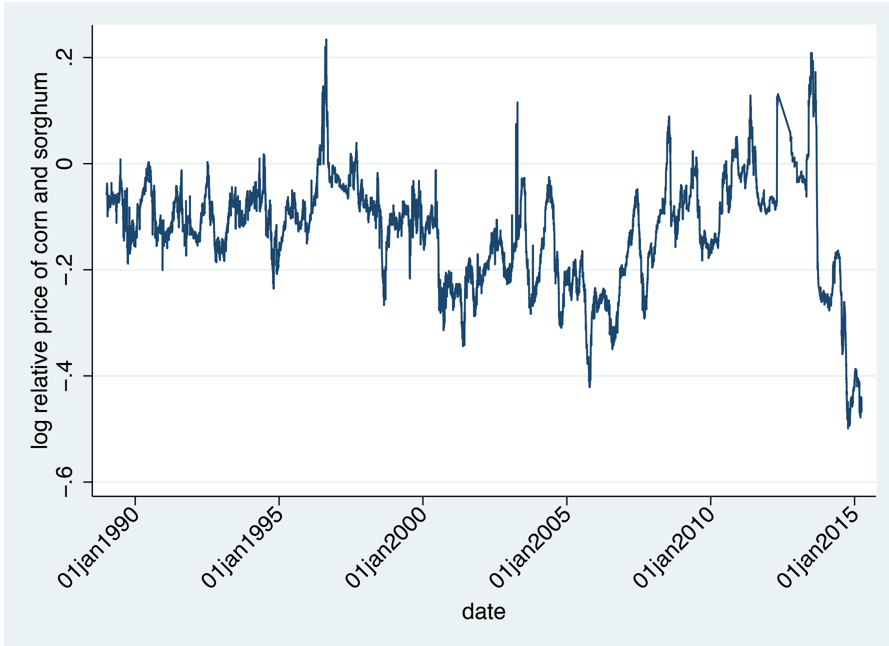
Panel A. 1/03/1989 – 4/01/2015				
Test	Statistic	5% Critical Value	Date of Maximal F-Statistic	Conclusion
UDmax	66.13	9.52	–	# breaks ∈ {1,2,3,4,5,6}
WDmax	75.98	10.39	–	# breaks ∈ {1,2,3,4,5,6}
Sup-F(1|0)	14.73	9.10	06/30/2000	At least one break
Sup-F(2|1)	7.99	10.55	07/17/2000	One break

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 ∈ {1,2,3,4,5,6}
WDmax	194.55	10.39	–	# breaks ∈ {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 ∈ {1,2,3,4,5,6}
WDmax	57.30	10.39	-	# breaks ∈ {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 % f sample. Robust standard errors with AR(1) prewhitening used for all tests (Bai and Perron, 1998).

Figure 1. Log Relative Price of Corn and Sorghum, January 1989 – April 2015



Note: Log relative prices are equal to log corn prices minus log sogrhum prices.

Figure 2. Normalized Trace Test for R<1 with Rolling Horizon = 4 Years

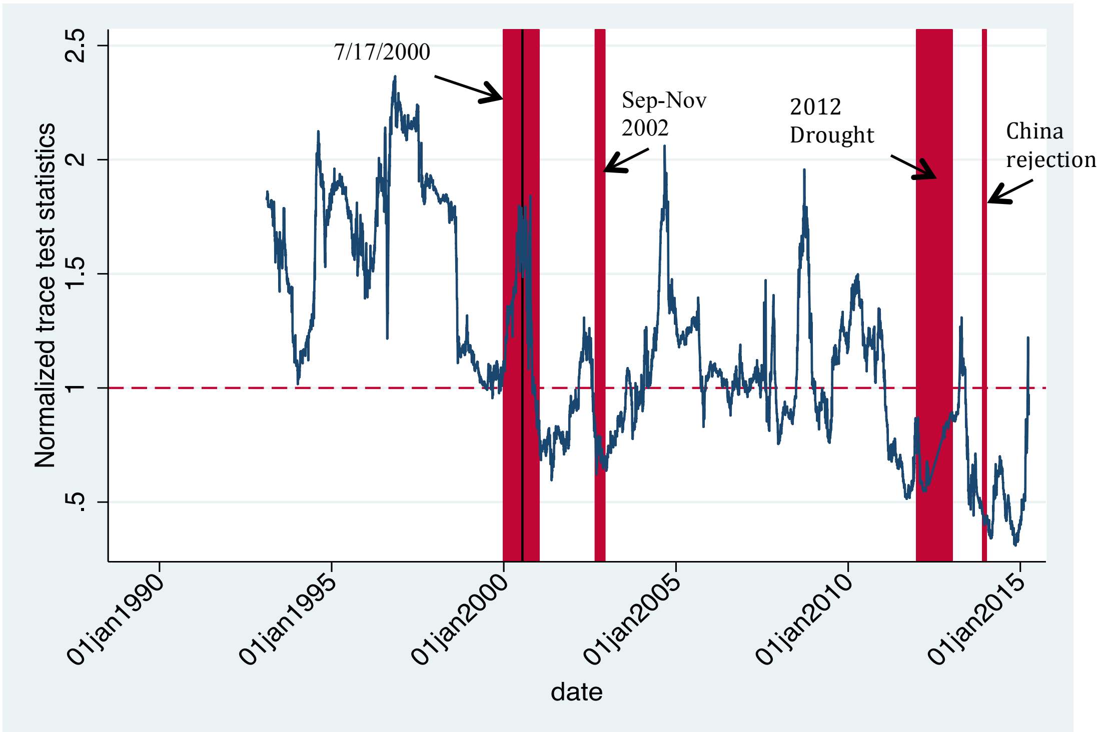
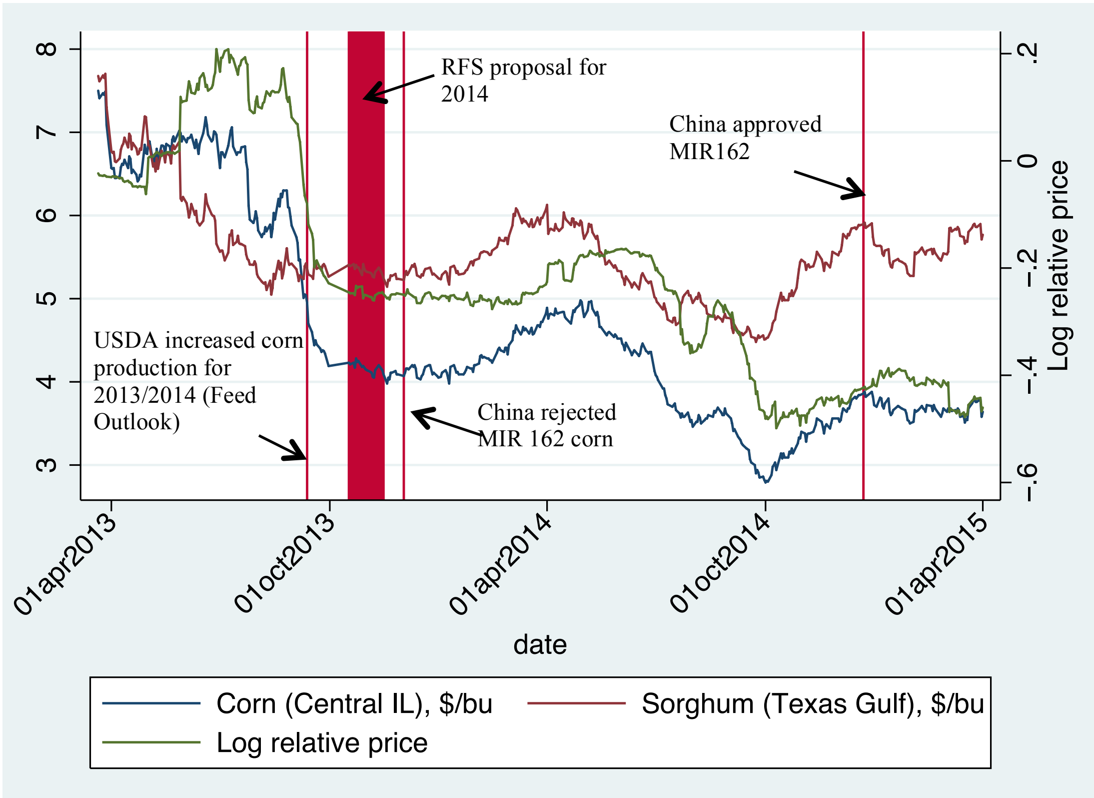


Figure 3. Relative Log Prices, April 2013 – April 2015



Note: Log relative prices are equal to log corn prices minus log sorghum prices.

Figure 4. U.S Exports of Corn and Sorghum to China, 2007 – 2014