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Abstract – Genetic modification of crops has revolutionized food production, but it remains controversial due to food safety and environmental concerns. A recent food safety scare provides a natural experiment on the corn market's willingness to accept unapproved genetically modified organisms. In 2000, a genetically modified corn variety called StarLink was discovered in the food-corn supply, even though it was not approved for human consumption. To estimate the price impact of this event, we develop the relative price of a substitute method, which applies not only to the StarLink event but also to rare events in other markets. We apply this method to measure the price impact of the StarLink contamination on the U.S. corn market. We find that the contamination led to a 7 percent suppression of corn prices that lasted for at least a year.

JEL Codes: Q11, Q18, C22

I. Introduction

Globally, plantings of the four main biotech crops (corn, cotton, soybeans, and canola) increased from 4 million acres in 1995 to 222 million acres in 2005. Almost 25 percent of global corn acres are now planted to genetically modified (GM) varieties. Compared to traditional plant breeding, genetic modification produces new varieties of plants more quickly and efficiently, and it introduces desirable traits into plants such as resistance to herbicides, insects, disease, drought and salts in the soil. Furthermore, ongoing GM crop research programs aim to improve the nutritional quality of food.

There exist huge potential benefits to producers, consumers, and the environment from GM crop technology. However, widespread controversy surrounds the commercial production and marketing of GM food. Much of the opposition to this technology is centered in the European Union. Opponents of GM technology claim that there may exist unknown health risks to those who consume GM food, and GM crops could impose huge costs on society by reducing biodiversity.

In this article, we assess the willingness of the market to accept contamination of the food supply by an unapproved GM corn variety called StarLink. In 1998, the U.S. Environmental Protection Agency (EPA) licensed StarLink for commercial production for animal feed and non-food industrial products but, unlike most other GM corn, the EPA did not approve StarLink for human consumption. Nonetheless, StarLink became commingled with non-StarLink corn and entered the human food supply. This commingling became public knowledge on September 18, 2000, when *The Washington Post* reported that traces of StarLink had been detected in taco shells. In the months that followed, hundreds of food products were recalled, scores of corn shipments were redirected, and several lawsuits were brought against Aventis CropScience, the developer of StarLink.

The StarLink contamination event constitutes a natural experiment. Accordingly, this article complements the existing literature, which typically uses laboratory experiments to estimate price discounts associated with GM food safety risk (e.g., Lusk et al. 2004, Shogren et. al. 1994). Natural experiments have several advantages over laboratory experiments (Harrison and List 2004). First, natural experiments enable an economist to observe the behavior of economic agents participating in actual markets rather than under artificial conditions. Second, the stakes are typically much higher and therefore more realistic in natural experiments. It would be difficult to simulate in a laboratory a global food safety scare like StarLink. Nevertheless, as Harrison and List point out, the market setting of a natural experiment eliminates any control of the economist over the experiment. Thus, it may be difficult to make reliable inference about the market effects of the event under study.

To overcome this difficulty for the StarLink case, we develop a new method that will be also useful for estimating the price impacts of other significant news events in commodity markets. Several methods for estimating price impacts exist in the literature. The most prominent methods are: (i) a simple comparison of average prices before and after the event, (ii) event studies, and (iii) a comparison of observed prices with predicted prices from a structural supply and demand model. We develop the relative price of a substitute (RPS) method, which exploits the equilibrium properties of the relative price of the commodity of interest to a substitute good. Heuristically, if the relative price is stable before the event but exhibits a structural break after the event, then preferences or relative technology must have been changed by the event. To estimate the magnitude of the price impact, we use forecasts from a cointegration model of the two prices. We find that StarLink contamination lowered U.S. corn prices by about 7 percent for at least a year.

The article proceeds as follows. In Section II, we discuss the U.S. corn market and the StarLink incident. We develop the RPS method for determining the price impact in Section III, before presenting results for the StarLink case in Section IV and the conclusion in Section V.

II. The U.S. Corn Market and the StarLink Incident

"Literally hundreds of barges and thousands of trucks and rail cars have been redirected as a result of containing extremely low levels of Cry9C-containing (i.e., StarLink) corn." (Gadsby, p.5)

The United States is the world's largest producer and exporter of corn, accounting for about 40 percent of global output and 65 percent of world corn exports. U.S. corn growers produce about 9.5 billion bushels per year (240 million metric tons), which translates into more than $17 billion in revenue for farmers. In most years about 60 percent of the annual U.S. corn harvest is fed domestically to cattle, hogs, chickens and other animals, and about 5 percent goes to non-food industrial uses, such as ethanol production. An additional 15 percent of the annual supply is used domestically for food products and 20 percent is exported. Approximately one third of annual U.S. corn exports go to Japan, a market that was dramatically affected by the StarLink event.

Aventis CropScience, a French multinational corporation, developed StarLink corn, and farmers first commercially grew it in the United States in 1998. Unlike most other GM corn, the U.S. government did not approve StarLink for human consumption. Instead, the EPA issued a "split" license, approving the corn as safe only for animal consumption and non-food industrial uses. StarLink was not approved for human consumption because it contained Cry9C, a protein that might cause allergic reactions in some humans. Cry9C is toxic to European corn borers and other insects, a desirable characteristic for bio-engineered corn.

On September 18, 2000 *The Washington Post* reported the detection of traces of StarLink in taco shells in the United States. Two months earlier, in July 2000, the EPA had received reports alleging adverse events linked to corn food products (U.S. Food and Drug Administration, 2001). As early as January 2000, Aventis sent the results of a farmer survey to the EPA, which showed that some StarLink corn was sold into channels where it should not have gone.[1] Even though companies selling StarLink claimed that they instructed growers to keep it separate from other

[1] *New York Times*, "1999 Survey on Gene-Altered Corn Disclosed Some Improper Uses" Section C, p.2, September 4, 2001.

crops, a number of growers claimed they never received any such warning.[2] These anecdotes suggest that the *Washington Post* story was not the first indication of contamination. In fact, in this paper we find that contamination first affected the corn market in July 2000.

The *Washington Post* story led to immediate food recalls of approximately 300 food products (Lin, Price, and Allen, 2002) and the fallout soon spilled into foreign markets. On October 26 2000, reports indicated the presence of StarLink corn in snack foods and animal feed in Japan (Taylor and Tick, 2001), the largest single foreign customer of U.S. corn. At the time of the contamination, StarLink was not approved for animal feed or human consumption in Japan. Similar discoveries of StarLink were reported in South Korea, where StarLink was not approved for any use. In addition, traces of StarLink were found in the Canadian corn supply, jeopardizing Canadian corn exports to Japan. The EU also expressed concern that some food products imported from the U.S. might contain StarLink.

In late September 2000, Aventis announced a plan to buy StarLink corn back from farmers under the supervision of the U.S. Department of Agriculture (USDA). Aventis extended this program, which offered a 25 cents premium per bushel, to grain elevators in October 2000. The repurchased StarLink corn was redirected to use for animal feed, where it traded at about a 5 percent discount relative to non-StarLink corn, although in the early stages of the incident the price discount reached as high as 10 percent (Lin et al. 2002). Formal analysis of price differences between StarLink and non-StarLink corn is infeasible because reliable data do not exist and because of difficulty in certifying non-StarLink corn for trade in spot markets. Furthermore, the existence of a two-tiered market was tempered by the fact that corn futures contracts on the

[2] In the fall of 2000, the Iowa Attorney General launched an investigation of a mailing of letters by Aventis to StarLink growers. The letters were reportedly mailed after the contamination became public knowledge and enclosed with the letters were copies of agreements the growers were asked to sign and return to Aventis. The letters were backdated to April 2000. The *New York Times* reported that many StarLink farmers had not signed such agreements and were unaware of restrictions on use of StarLink (*New York Times*, “1999 Survey on Gene-Altered Corn Disclosed Some Improper Uses” Section C, p.2, September 4, 2001.)

Chicago Board of Trade (CBOT) could be filled with StarLink corn before and after September 18, 2000.

Aventis voluntarily withdrew registration for StarLink in mid October 2000. This withdrawal and the buyback programs meant that no StarLink corn should have been planted in the 2001 and subsequent crop years. Thus, StarLink was only produced in three years, 1998, 1999, and 2000. Production peaked in 2000, when StarLink was planted on 350,000 acres, producing about 52.5 million bushels. This volume constituted less than 1 percent of the total U.S. corn crop. Despite the small volume, StarLink contamination was widespread. Table 1 shows that, between April and September 2000, 67 percent of feed corn shipments destined for Japan tested positive for StarLink. The measurable proportion of positive tests declined to 47 percent from October 2000 to March 2001, and then to 15 percent from April to September 2001. This evidence indicates that StarLink had contaminated the corn supply a few months before the September *Washington Post* story and that the contamination persisted long after production of StarLink officially ceased. In December 2002, more than two years after StarLink was withdrawn from the market, a cargo of food corn shipped to Japan tested positive for StarLink. US corn processors and Japanese importers continued monitoring and testing for StarLink through 2005.

According to U.S. Embassy staff in Tokyo, “Due to the StarLink issue, imports of U.S. corn fell about 1.3 million metric tons in CY2001, a drop of 8 percent” (USDA, Foreign Agricultural Service, GAIN Report #JA2001). This drop is evident in Figure 1, which shows the weekly volume of U.S. corn export sales to Japan from April 2000 through March 2001. The solid line in Figure 1 traces weekly U.S. corn exports to Japan during the year of initial contamination. The dashed line shows weekly average exports to Japan over the previous three years. Figure 1 reveals that for several weeks in 2000, export sales were down from the average over the previous three years. In July 2000, export sales dropped sharply to 100,000 mt from a three-year average of 300,000 mt. This drop is consistent with results from the Japanese testing of inbound U.S. corn.

In February 2001, the USDA’s Grain Inspection, Packers and Stockyards Administration (GIPSA) issued a directive on sampling and testing for StarLink corn. GIPSA calculated statistical confidence levels for approved StarLink testing procedures. Figure 2 displays the essential GIPSA results. The horizontal axis in Figure 2 shows the hypothetical percentage of StarLink in a single cargo of corn. The vertical axis shows the corresponding “false positive” probability of accepting a cargo as non-StarLink. Suppose a cargo of corn is destined for Japan and the actual level of contamination is one tenth of one percent (i.e., 0.10 percent), shown by point X in Figure 2. GIPSA found that there is more than a 9 percent chance that the cargo in question would be falsely determined to be StarLink free through accepted testing procedures. With a contamination level of 0.10 percent, there could be millions of kernels of StarLink tainted corn in this cargo, which could later show up in food products. This example illustrates why it is almost impossible to meet a zero percent tolerance standard (Lin et al. 2002) and why the StarLink contamination caused such a serious market disturbance. The StarLink contamination event was particularly disruptive because a relatively large share of the market had zero tolerance for its use. In total, zero-tolerance markets accounted for up to 25 percent of the demand for U.S. corn.

We hypothesize that the customers for U.S. corn with a zero-tolerance standard knew that this standard was virtually impossible to meet and therefore faced a high probability of buying contaminated corn in 2000 or later. This possibility reduced the demand for U.S. corn. Because corn is storable, current prices are a function of both current demand and expected future demand, so the price would have dropped when traders realized that contamination was possible. This price drop estimates the willingness of the market to accept StarLink contamination of the corn supply. In the next section, we develop a method for estimating both the size and timing of this price drop. We then apply our method to the StarLink case.

III. Estimating the Price Impact

A. *Existing Methods*

Several approaches to estimating the price impact of market news events exist in the literature. The three main approaches are: (i) compare average prices before and after the event, (ii) conduct an event study, and (iii) compare observed prices with predicted prices from a structural supply and demand model. The distinguishing feature of each method is the way the benchmark price is computed. The benchmark price is an estimate of the price that would have existed had the event not occurred. In the first approach, the benchmark is the average price of the commodity over some prespecified period before the event. In the second approach, the benchmark price is computed using asset-pricing theory. In the third approach, the benchmark price is computed from estimated supply and demand functions.

The first method, comparing prices before and after the event, performs well when the event timing is known and when there are no other price shocks around the time of the event. Such other price shocks would contaminate the estimated price impact. Connor (2001) uses this method to estimate the overcharges in the lysine price fixing conspiracy of 1992-1995. McKenzie and Thomsen (2001) use a variant of this method to study the effect of recalls for *E. Coli* on beef prices. McKenzie and Thomsen average over 55 different recall events, which yields a more powerful test for significance and helps reduce the noise from price shocks unrelated to *E. Coli*. This method can perform poorly when there is only one observation of the event because it is difficult to demonstrate a statistically significant effect using only pre- and post-event prices. Other methods obtain significant results by adding information to the problem in the form of a model structure, a longer time series, or other variables.

The event study approach (MacKinlay 1997) uses portfolio theory to determine a benchmark price. Because portfolio theory is readily applicable to stock prices, such studies often examine the impact of events on the stock prices of the companies involved, rather than estimating the direct effect on a commodity price. Examples of event studies in agriculture include Thomsen and McKenzie's (2001) study of beef recalls for *E. Coli*, Henson and Mazzocchi's (2002) study of BSE in the UK, and Dohlman, Hall, and Somwaru's (2002) analysis of regulation of biotech crops. As per the standard event study approach, these papers average over multiple companies that were affected by the incidents to produce a more powerful test for significance of the event. The effects of these events on the companies are heterogeneous, but these studies aim to estimate the average effect rather than separate effects on each company.

The third method requires estimating a structural supply and demand model. Such a model enables testing for significant price impacts through structural break tests or by testing for the significance of shifter variables. For example, Burton and Young (1996) determine the effect of BSE on UK meat demand by estimating the effect of BSE related media reports. The literature on structural supply and demand models is extensive, in part because it is notoriously difficult to specify such models correctly. Misspecification can be costly when the goal of the analysis is to identify changes in structure; apparent changes in structure may result purely from an inadequate specification (Chalfant and Alston 1988).

In the StarLink case, none of the three existing methods are optimal. The main drawback of the third method is the difficulty in correctly specifying a structural supply and demand system for the world corn market. Corn demand is very complicated because there are multiple customers, including domestic food, domestic feed, foreign food, and foreign feed. Each of these customers has a different demand function and would be affected differently by the StarLink incident. Nonetheless, it is possible that a carefully constructed structural model could yield insight into the effects of the StarLink incident.

The first two methods are not well suited to the StarLink case because we only have one observation of the event and the event date is not known with certainty. Also, traditional event studies use portfolio theory to determine the benchmark, whereas corn price dynamics are usually explained using rational storage models (Williams 1987). Empirically, the common event study approach of using broad stock indices as benchmarks may lack precision because corn price changes are almost uncorrelated with stock index returns (Dusak, 1973). Next, we propose an approach to estimating price impacts that takes advantage of the high quality price data that are available for many commodities. This method applies not only to the StarLink case, but could also be used for other price impact studies of rare events.

B. *The Relative Price of a Substitute (RPS) Method*

Our method uses the time series behavior of the price of the commodity of interest relative to a substitute good to make inference about the price impact of a market event. This approach brings extra information to the problem in the form of the price of a substitute good, but avoids the specification problems associated with the estimation of a full structural supply and demand model. Instead of estimating a full structural model, we focus on the implications of such a model for relative price dynamics. We identify these dynamic properties, test if they are stable before the event, and determine whether they change after the event. A change in a previously stable relative price implies a change in the underlying supply and demand structure and enables direct estimation of the price impact of the event. In essence, the RPS method is a reduced form approach that avoids the potential specification error associated with estimating a structural system, and it allows for inference when data on quantities and other arguments of the supply and demand functions are unavailable.

As a simple example to motivate the RPS method, consider a simple two-good economy where consumers have Cobb-Douglas preferences and where the supply curves for the two goods are perfectly inelastic. From the inverse demand functions, the relative prices have the following structure:

$$\log(P_{1t} / P_{2t}) = \log(\theta/(1-\theta)) + \log(Q_{2t} / Q_{1t}) , \quad (1)$$

where P_{it} is the price of good i in period t, Q_{it} denotes the quantity of good i in period t, and θ is the Cobb-Douglas parameter. If there are no relative technology shocks, then the relative quantity and the relative price are both constant. If preferences (θ) change, then the log relative price changes according to equation (1). Similarly, if relative technology changes, then the relative quantity and the relative price both change. Thus, one can test for a change in preferences or relative technology by testing for a change in the relative price.

In this simple example, the relative price is insulated from income shocks and from any technology shocks that may affect the supply of each good equally. By eliminating these shocks, we make it easier to identify preference and relative technology shocks. The assumptions of Cobb-Douglas preferences and perfectly inelastic supply are too simplistic for most applications. However, whatever the supply and demand characteristics of the commodity and its substitute, one can always write down an expression for the relative price as a function of quantities and of supply and demand shifters such as income, factor prices, and prices of other goods, i.e.,

$$\log(P_{1t} / P_{2t}) = g(Q_{1t}, Q_{2t}, Z_t), \tag{2}$$

where Z_t denotes supply and demand shifters and $g(\cdot)$ is an unspecified function. To test for a change in preferences or relative technology, one needs to test for a change in the relative price function g. Our insight is that such a test need not require that the function g be correctly specified or even that it be specified at all.

To see why the function $g(\cdot)$ in (2) does not need to be estimated, consider again the Cobb-Douglas example in (1). Suppose that $\log(Q_{2t} / Q_{1t})$ varies over time, but has a constant mean. In other words, suppose that relative technology is subject to temporary shocks, but reverts back to its mean value in the long run. These temporary shocks induce serial correlation in $\log(P_{1t} / P_{2t})$. Thus, to test for a change in preferences or relative technology, one could test for a change in the mean of $\log(P_{1t} / P_{2t})$ allowing for serial correlation. There is no need to include data on quantities in this test because the serial correlation captures the essential dynamic features of the quantity data. Obviously, if quantity data were available, one could test for a change in the mean relative price conditional on quantity. Such a test would be more powerful than the unconditional test, but may be severely biased if the conditional mean function were not correctly specified (Chalfant and Alston 1988).

In general, if supply and demand shifters have only a transitory effect on relative prices, then a shift in the mean relative price implies a change in preferences or relative technology. If, however, these shifter variables have permanent effects on relative prices, then the mean relative price is not constant, even if preferences and relative technology are constant. In other words, if these variables have permanent effects on relative prices, then the relative price contains a unit root and any changes in preferences or relative technology cannot be identified separately from shocks to the shifter variables. Therefore a breaks test could falsely attribute to the market event a level shift induced by the shifter variables. This result emanates from a failure of "conditional independence given predictive proxies" (White, 2006), i.e., the shifter variables are not included in the analysis, but are correlated with the event under study.

To identify the price impact in this context, one must first find a cointegrating relationship between relative prices and other relevant variables not caused by the market event. This cointegrating relationship provides a stable conditional mean function for the relative price, and therefore a parameter shift in the cointegrating relationship indicates a change in preferences or technology. Thus, the RPS method requires a stable pre-event relative price relationship of the form

$$\log(P_{1t} / P_{2t}) = \mu + \beta' Z_t + u_t \,, \tag{3}$$

where u_t is a stationary random variable and Z_t denotes supply and demand shifters. The Z_t variables contain a unit root and are only needed in the analysis if the log relative price is not stationary. To determine whether an event has a significant price impact, we test for a shift in the parameter μ during the event.[3]

[3] In principle, a change in preferences or relative technology could also change β. In such a case, the price impact would be nonstationary and a function of Z_t. Although the RPS method applies to such cases, we focus our discussion on the case of a constant price impact.

Testing for parameter shifts, or structural breaks, has a long history in the econometrics and statistics literature. When there is one known break date, the *F*-test of Chow (1960) is commonly used. When the break point is unknown, statistical inference becomes more difficult because the usual *F*-statistic has a nonstandard distribution. Many authors, including Andrews, Lee, and Ploberger (1996), have addressed this problem. When the number of possible break points is unknown, the problem becomes even more complicated. Bai and Perron (1998) solve this problem with a testing strategy that searches for the number and location of the breaks simultaneously. The test statistics proposed by Bai and Perron are sup-*F* tests, i.e., the relevant test statistic is the maximum *F*-statistic over all possible break points. In other words, it is the maximum value of the familiar Chow (1960) test. The Bai-Perron tests apply to stationary data, i.e., tests for a change in μ in (3) in the case where there are no Z variables. For nonstationary data with cointegration, Hansen (1992) and Hansen (2003), among others, have proposed breaks tests.

The RPS method enables estimation of the timing of the event. Whereas the econometrician may know approximately when the event occurred, the exact time that it hit the market is often unknown. Using structural break tests for unknown break points (e.g., Bai and Perron 1998), the RPS method determines both whether a significant event occurred and when it occurred. The precision of this timing estimate varies depending on the characteristics of the event. For storable commodities, news of current or future changes in preferences or relative technology leads to an immediate price effect and so the timing of the event can be precisely estimated. On the other hand, market developments such as a gradual increase in relative production efficiency generate a gradual change in the relative price and an imprecise estimate of the timing. Thus the precision of the estimate of the event timing reveals the nature of the event; precisely estimated event dates correspond to sudden market events.

Once the significance and timing of the event have been determined from the relative price dynamics, the final step is to estimate the impact on the absolute price of each good. This estimation requires decomposing the relative price change into the absolute price changes for each of the two goods. To estimate the price impact (PI) for each good, we compare observed prices after the break to forecasts made under the assumption that the event did not occur. The price impact of the event equals the mean forecast error. The precision of the forecasting model does not affect the validity of this method, although if the forecasting model is known to be accurate, then the PI estimates will be more precise. We assume only that the forecasting model is unbiased and that the forecast error variance can be estimated using pre-event data. Thus, for example, the forecasting model could use a much shorter sample than the breaks tests if the absolute price dynamics are less stable than relative prices.

To improve the precision of the PI estimates, we use the magnitude of the shift in the relative price, which is estimated as part of the breaks testing procedure. Specifically, the difference between the PI's must equal the effect on the log relative price, so that $PI_1^0 - PI_2^0 = \mu_a - \mu_b$, where the subscripts b and a indicate values of the parameter μ in (3) before and after the event, respectively, and PI_1^0 and PI_2^0 denote the true price impacts for the two goods. Estimates of μ_a and μ_b arise as by-products of the breaks tests.

Assuming that the forecasts are unbiased in the absence of the market event, the mean forecast error for good one equals PI_1^0 and the mean forecast error for good two equals $PI_1^0 - (\mu_a - \mu_b)$. Because the forecasts are made over various horizons, and because they are made using the same information set, the forecast errors are heteroskedastic and correlated. Thus, we estimate PI_1^0 using weighted least squares, implying that the estimated price impact for good one is

$$PI_1 = \frac{\iota'\Omega^{-1}\varepsilon}{\iota'\Omega^{-1}\iota}, \tag{4}$$

where

$$\varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 + \mu_a - \mu_b \end{bmatrix}, \quad \Omega = \mathrm{var}(\varepsilon) = \mathrm{var}\begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \end{pmatrix},$$

ι is a $2h\times1$ vector of ones, and ε_1 and ε_2 denote $h\times1$ vectors of forecast errors for the prices of goods one and two over the h periods following the break. To estimate Ω under the null hypothesis of zero price impact, we apply the forecasting model to pre-event data and compute the variance-covariance matrix of the pre-event forecast errors. Using standard formulas, the standard error of PI_1 is

$$s.e.(PI_1) = \sqrt{\mathrm{var}(PI_1)} = \sqrt{\frac{\iota'\Omega^{-1}\,\mathrm{var}(\varepsilon)\Omega^{-1}\iota}{(\iota'\Omega^{-1}\iota)^2}} = \frac{1}{\sqrt{\iota'\Omega^{-1}\iota}}\,. \tag{5}$$

Thus, a standard 95% confidence interval for PI is $\left(PI_1 - 2(\iota'\Omega^{-1}\iota)^{-1/2}, PI_1 + 2(\iota'\Omega^{-1}\iota)^{-1/2}\right)$.

The precision of the price impact estimate depends on how accurate the forecasting model is; from the expression in (5), the smaller is the forecast error variance, Ω, the smaller is the standard error. The precision of PI_1 is also likely to be greater if the price impact occurs abruptly. Given that forecasts of more distant prices are less accurate than forecasts of nearby prices, the longer the forecast horizon required to capture the price impact, the more likely that the estimate will be significantly contaminated by other shocks. Alternatively, if the price impact is abrupt, then it is easier to separate it from other price shocks.

In summary, the RPS method involves three steps:

1) Test for a stable (conditional) mean relative price before the event,
2) Test for a break in the (conditional) mean relative price around the event, and
3) Estimate price impact as the weighted average error in forecasts of post-event prices.

In the next section, we use the RPS method to estimate the price impact of the StarLink contamination event. To conclude this section, we make several remarks about the RPS method.

Remark 1. Because it makes inference from a time series containing a single market event, the RPS method only identifies a sustained change in the parameters of the supply and demand system. It does not identify transitory shocks that affect relative prices and then decay quickly.

This feature of the RPS method implies that a stationary relative price (or a stable cointegrating relationship between the relative price and some other variables as in (3)) is synonymous with the absence of a sustained change in preferences or relative technology. To identify short-lived preference or relative technology shocks, one requires multiple observations of the event as in the event study approach, or careful analysis of the type in White (2006).

Remark 2. The usefulness of the RPS method for identifying changes in preferences and relative technology depends on the frequency of changes in these features. If they change frequently, then it is difficult to identify a particular change due to a particular event. If these changes are rare, then tests for changes are more powerful. Similarly, the closer is the price relationship between the two goods, i.e., the less serial correlation in the relative price, the more powerful is the method. These features suggest that finding a substitute good with a stable close relationship with the good of interest is an important component of the RPS method.

Remark 3. A cost of avoiding structural estimation is that the RPS method does not capture events that impact the prices of both goods. For example, if a change in preferences reduces demand for both goods equally, then relative prices will not change. Thus, the RPS method is most efficient when the chosen substitute good is not directly affected by the event under study.

Remark 4. By focusing on relative prices we filter out shocks that are common to both prices, which enables testing for a significant price effect without specifying a full demand and supply system. Our focus on relative prices is also important because absolute commodity price series are very persistent and typically contain a unit root (Ardeni 1989, Goodwin and Piggott 2001). When a series contains a unit root, every shock has a permanent effect on the price, making it impossible to identify a particular permanent shock without filtering out the shocks that are not of interest.

IV. Results for the StarLink Case

A. *Relationship between Corn and Sorghum Prices*

The RPS method applies to the StarLink case because the contamination comprised a single market event that potentially had a sustained impact on corn prices. Furthermore, corn possesses a close substitute in sorghum. Over 90 percent of U.S. sorghum is used for animal feed and it is the second most important U.S. feed grain behind corn. Globally, 50 percent of sorghum is used for human food although the majority of U.S. sorghum exports go into animal feed. The bushel weight and nutritional values of sorghum are the same as for corn, which makes it a very close animal feed substitute for corn. Furthermore, sorghum has no GM varieties, meaning that both domestic and foreign customers looking to avoid StarLink contamination could have substituted towards sorghum. However, even if no feed customers substituted sorghum for corn and the entire reduction in corn demand originated from human food customers, the relative price of corn to sorghum would still have fallen and the RPS method would apply directly.

The relative price of corn to sorghum was remarkably stable over a long period of time leading up to the StarLink incident. From January 1980 through December 1989, the average difference between monthly log corn and sorghum prices at the Louisiana Gulf was 0.060, or about 6 percent.[4] From January 1990 through December 1999, the average log price difference was very similar at 0.057. During this latter 10-year period, the relative production of corn doubled. Specifically, the annual sorghum crop averaged about 10 percent of the annual corn crop during the 1980s, but through the 1990s this ratio dropped steadily, reaching 5 percent by the end of the decade. Nonetheless, relative prices fluctuated around the same level throughout the two decades, indicating that demand for the two commodities is very elastic, which is implied by close substitutability. From January 2000 through September 2002, the average log price difference between corn and sorghum was –0.016. Thus, corn went from commanding a 6 percent

[4] These data measure monthly average export bids for grain delivered to Gulf export elevators. The data are publicly available at the website http://www.ers.usda.gov.

premium over sorghum before 2000 to a 2 percent price discount after 2000. This 2000-2002 period includes the StarLink contamination event because there was no significant volume of StarLink in the market prior to the end of 1999.

To isolate the exact period over which StarLink influenced corn prices, we apply the RPS method using daily data. The data are daily spot prices and the sample begins in January 1989 and runs through August 2002. The corn prices are average daily processor bids in the central Illinois market and the sorghum prices are average daily bids from the Louisiana Gulf market. The data source is the Commodity Research Bureau. The central Illinois and Louisiana Gulf spot markets are among the most liquid in corn and sorghum, respectively.

Prior to 2000, the mean log relative price in these data averaged –0.09, which is 0.15 less than the average of 0.06 for monthly Gulf corn and sorghum. This difference of 0.15 reflects the cost of transportation of corn from Illinois to the Gulf. While the spatial price difference between central Illinois and the Gulf could add noise to the analysis, the use of prices from liquid markets reduces noise in the estimated price impact. Nonetheless, we check the robustness of our results to the market location and to the relatively short sample using monthly USDA data from Kansas City and the Louisiana Gulf.

We illustrate the long-term stability of the relative price before the commercial production of StarLink by showing that absolute corn and sorghum prices were cointegrated with a (1, –1) cointegrating vector. We do this by demonstrating presence of a unit root in log prices but no unit root in the log relative price. Such cointegration between corn and sorghum can be represented by the equation

$$(c_t - s_t) = \mu + z_t \tag{6}$$

where c_t denotes the log price of corn, s_t denotes the log price of sorghum, and z_t is a stationary error term. We apply the augmented Dickey-Fuller test to $(c_t - s_t)$ and present the results in Table 2. The test strongly indicates that the prices of corn and sorghum were cointegrated prior to 2000; both price series contain a unit root, but that the relative price is mean reverting. Next, we use the structural break tests of Bai and Perron (1998) to determine whether or not the relative price remained stable through the period containing the StarLink incident.

B. *Structural Break Tests for Stability*

Having found a cointegrating relationship between corn and sorghum over the decade from 1989-99, we expand the sample to include the StarLink period and test for stability in the relative price. A break in the relative price indicates that whatever shocks caused the break had a lasting impact on the parameters. The cointegration results in Table 2 suggest that there were no pre-2000 breaks (otherwise cointegration would have been rejected), so the breaks tests provide a robustness check on the cointegration results, as well as providing tests for the impact of the StarLink event. We test for a break in the parameter μ in (6) using the Bai-Perron testing procedure.

The procedure of Bai and Perron (1998) begins with a test of the null hypothesis of zero breaks against the alternative of one break. If the null hypothesis is rejected, then the first break is taken as given and a test is conducted for a second break. The procedure continues until the null hypothesis of no further breaks is not rejected. All test statistics in this method are sup-*F* tests, i.e., the relevant test statistic is the maximum *F*-statistic over all possible break points. In other words, it is the maximum value of the familiar Chow (1960) test. To improve the robustness of their procedure, Bai and Perron also suggest performing a double-maximum test, which is the maximum *F*-statistic over all possible break points and over the total number of breaks. This statistic provides a test against the alternative hypothesis of some unspecified number of breaks. The results from breaks tests are given in Table 3. All tests provide strong evidence of a break in mid July of 2000. The sequential procedure of Bai and Perron suggests that there are two breaks, the first in July 2000, and the second in December 2001. As expected, the procedure detects no breaks prior to 2000.

The findings of the breaks tests are consistent with Figure 3, which shows the log relative price of corn and sorghum through the whole sample. From 1989-2000, the log-relative price never traveled far from its mean of –0.09, apart from a brief spike during the corn shortage of 1996.[5] In July 2000, the log relative price dropped abruptly to –0.24, which translates into approximately a 15 percent drop in the relative price. This drop occurred within two weeks, beginning on July 17, as indicated by the breaks tests. The abruptness of the drop indicates that it was a swift market reaction to a piece of news, rather than a gradual evolution towards a new equilibrium. The relative price remained low for about a year and a half until December 2001, when it began to creep up towards its previous value. By the summer of 2002 the average log relative price had increased to –0.15, which is two thirds of the way back to its original point.

To test the robustness of our breaks tests to the market location and to the relatively short sample, we supplement our daily data with monthly data spanning the period 1975-2002. These data provide 14 more years of pre-StarLink data than are available at the daily frequency. We use monthly corn prices in the central Illinois, Kansas City, and Louisiana Gulf markets and monthly sorghum prices for Kansas City and the Gulf.[6] These data enable us to test whether the relative price of corn and sorghum was stable not only for the 11 pre-StarLink years back to 1989, but the 25 years back to 1975. Also, by using corn and sorghum prices from the same markets, we control for any possible changes in the cost structure along the supply chain for these commodities.

We apply the Bai-Perron tests to the relative price of corn and sorghum in the Gulf market and in the Kansas City market. For both markets, the test procedure finds only one break in the sample. This break was in July 2000. We also apply the Bai-Perron tests to the monthly relative

[5] Due to a poor harvest in 1995, total stocks of corn were lower during the summer of 1996 than at any point since 1976. These low stocks caused a brief spike in the price of corn that quickly reversed itself; the breaks tests presented in Table 3 show that this episode did not constitute a statistically significant mean shift.

[6] These data are publicly available at http://www.ers.usda.gov. The Kansas City data measure truck bids for grain delivered to Kansas City and the Gulf data measure export bids for grain delivered to Gulf export elevators.

price of central Illinois corn to Gulf sorghum. The results mirror those for daily data with these markets and also indicated one break in July 2000. None of the monthly relative price series indicate a second break in December 2001, as found with the daily data. This result arises because December 2001 is too close to the end of the sample in the monthly data. These tests indicate that the relationship between corn and sorghum after July 2000 was different than it had been at any time since at least 1975.

Both the daily and monthly analyses point to a break in the relative price of corn and sorghum that occurred two months before the *Washington Post* reported that StarLink had been found in taco shells. Given that the U.S. grain handling system was not prepared to handle the split licensing of StarLink, it is likely that traders foresaw the impending disaster and substituted away from corn towards sorghum. This evidence is supported by Japan’s decision to start testing for StarLink in April 2000 and by information from Aventis early in 2000 suggesting possible contamination.

The minimal reaction of corn and sorghum prices to the *Washington Post* article further indicates that the article was not news to the market. On Monday September 18, the day of the article, the central Illinois corn price was unchanged from the previous Friday at $1.54 per bushel. On Tuesday September 19, the price dropped to $1.51, but it was back up to $1.60 by the end of the week. During this same week, the price of sorghum increased, leading to a slight drop in the relative price of corn to sorghum. The log relative price averaged –0.27 during the week preceding the article, –0.30 during the week of the article, and –0.29, –0.27, and –0.23 in the three following weeks. Thus, any effect of the *Washington Post* story on corn prices was minor and disappeared within two weeks. This result is consistent with that of Golub et al. (2004), who applied the event study method to stock returns for 17 agribusiness firms with links to the corn industry. Only one of the 17 companies, Corn Products International, exhibited significant negative abnormal returns around September 18. Moreover, on Friday September 15 Corn Products International announced a 40 percent drop in expected third quarter earnings for reasons unrelated to StarLink. Therefore, the significant result for this company was likely unrelated to the StarLink event.

Although the breaks tests show that the relative price of corn and sorghum dropped by 15 percent, the tests do not reveal how much of the relative price drop was due to a decrease in the price of corn and how much was due to an increase in the price of sorghum. In the final step in the RPS method, we estimate the price impacts on corn and sorghum as the weighted average error in forecasts of post-event prices.

C. *Estimating the Price Impact*

Because corn and sorghum prices are cointegrated, we form an error correction model (ECM) for forecasting. An ECM exists whenever there is cointegration in a set of time series (Engle and Granger 1987). The ECM is:

$$\Delta c_t = \alpha_c z_{t-1} + \gamma_c(L)\Delta c_{t-1} + \delta_c(L)\Delta s_{t-1} + \varepsilon_{ct}$$

$$\Delta s_t = \alpha_s z_{t-1} + \gamma_s(L)\Delta c_{t-1} + \delta_s(L)\Delta s_{t-1} + \varepsilon_{st} \qquad (7)$$

where $\gamma_c(L)$, $\delta_c(L)$, $\gamma_s(L)$, and $\delta_s(L)$ are polynomials in the lag operator and $z_t = c_t - s_t - \mu$ is the error correction term as defined in equation (6). The parameters α_c and α_s measure the response of corn and sorghum prices to deviations from the long-run trend. The closer α_c and α_s are to zero, the longer it takes for the series to revert to their long-run trend after a shock.

Table 4 presents the estimates of the ECM using daily data up to the end of 1999, i.e., before the StarLink contamination. The estimated value of the error correction parameter for corn, α_c, is –0.024. This value indicates that on average the daily corn price adjusts to correct 2.4 percent of any deviation from the long-run trend, implying that the half-life of a typical shock is 28.5 trading days, i.e., just less than 6 weeks. This reversion is somewhat slow but is significantly different from zero. The slow reversion indicates that corn and sorghum can deviate from their long-run relationship for long time periods. The error correction parameter for sorghum is –0.005 and is not significantly different from zero, indicating that it is primarily the corn price that reacts to restore the long-run equilibrium relationship between these two commodities.

Using the ECM, we forecast corn and sorghum prices from July 17, 2000, which is the breakpoint suggested by the Bai-Perron tests. The forecast horizon ends on August 25, six weeks after the breakpoint. This interval allows time for the price series to settle at new levels after the break. For each day in this six-week period, we compute the difference between the observed prices and the forecasts made on July 14, the last trading day before the break. Figure 4 shows the forecast errors for corn and sorghum, as well as the forecast error in the log relative price. It is evident that the initial shock on July 17 manifested itself in the Gulf sorghum market. Over the two days from July 17, the price of sorghum jumped 8 percent above what was expected. It wasn't until the following week of July 24-28 that the central Illinois corn price reacted, dropping by 6.5 percent. On Friday July 28, two weeks after the initial shock, the log corn price was 0.064 below its predicted value and log sorghum was 0.081 above its predicted value. By this time, the total forecast error on the relative price was –0.145, which is close to the total relative price change of –0.154 estimated in the breaks analysis above. Both variables stayed at these levels for a full six weeks until the end of August.

To estimate the price impact on corn, we apply the weighted least squares method in equation (4) to the forecast errors over this six-week horizon. We obtain a price impact estimate of –0.068 for corn, with a standard error of 0.013, implying that a 95 percent confidence interval for the price impact is (–0.042, –0.094). Because these numbers measure log changes and are small, they can be interpreted as approximate percentage changes. Thus, we can be 95 percent confident that the interval between –4.2 percent and –9.4 percent contains the true corn price effect.

To compare this estimate to that from a conventional event study, we took July 17 as the event date and performed an event study using daily log returns on the Russell 3000 stock index (r_t) as the benchmark. We estimated the equation $\Delta c_t = \alpha + \beta r_t + u_t$ using data from 1/1/99-7/10/00, and obtained the OLS estimates $\hat{\alpha} = 0.00$ and $\hat{\beta} = -0.10$. Over the two-week period from July 17 to July 28, the estimated cumulative abnormal return on corn was $CAR = \sum_t (\Delta c_t - \hat{\alpha} - \hat{\beta} r_t) = -0.060$.[7] Because the OLS estimate of β was not significantly different from zero, we repeated the analysis with β=0, and obtained $CAR = -0.051$. These CAR estimates are insignificantly different from zero, with 95 percent confidence intervals of (–0.125, 0.027) and (–0.122, 0.026), respectively. Thus, the RPS method yields more precise estimates of the price impact than the event study method. Moreover, using the relative price of corn to sorghum enabled us to identify the event date using the RPS method, whereas we took this date as given for the event study estimate.

The two largest price changes in the event period occurred on July 18 when the Gulf price of sorghum jumped from $1.78 to $1.90 per bushel and between July 21 and 26 when the central Illinois price of corn dropped from $1.54 to $1.47 per bushel. These two price changes are apparent in Figure 4 and constitute the majority of the relative price shift that was detected by the breaks tests in Table 3. The fact that there were no substantive shocks to either price for an entire month after the initial shocks increases confidence in the estimated price impact (PI). In fact, using forecast errors only for the two weeks up to July 28, the estimated PI is –0.067, compared to –0.068 for the six weeks up to August 25. When we extend the forecast horizon a further six weeks to October 6, the PI estimate becomes –0.074. The PI estimate changes little when we extend the forecast horizon because the forecasts of distant corn and sorghum prices are imprecise, so they receive a low weight in the weighted least squares PI estimator and hardly influence the PI estimates.

In the two weeks prior to July 17, 2000, both corn and sorghum prices drifted downwards. Consequently, beginning the event period before July 17 would increase the forecast errors and therefore the PI estimates of the effect on corn prices. However, because both corn and sorghum

[7] The CAR equals the sum of the estimated abnormal returns over the window from July 17 – July 28, where abnormal returns are defined by the benchmark model $\Delta c_t = \alpha + \beta r_t + u_t$, which in turn is motivated by the capital asset pricing model (CAPM). See MacKinlay (1997) for more details on the event study method.

prices drifted in the same direction in these two weeks, it is unlikely that the StarLink effect began before the 17th. Thus, we conclude that the StarLink contamination affected the market beginning on July 17 and our best estimate of the PI is –0.068.

V. Conclusion

The U.S. is the world's largest producer and exporter of corn, and the large-scale production of genetically modified corn in the U.S. has generated international debate. The StarLink contamination incident heightened this debate. StarLink corn was first commercially grown in the United States in 1998 but was never approved by the U.S. government for human consumption. Instead, the Environmental Protection Agency issued a “split” license, approving the corn as safe only for animal consumption. StarLink became commingled with non-StarLink corn and found its way into U.S. and foreign food products and bulk export cargoes. Upon the release of public news of this contamination, hundreds of food products were recalled.

In this article, we develop the relative price of a substitute (RPS) method for evaluating the price impact of rare market events. We apply the RPS method to measure the price impact of the StarLink contamination on the U.S. corn market. Using the 25-year stable relationship between the prices of corn and sorghum, we find that the StarLink incident triggered about a 7 percent drop in the price of corn that persisted for at least a year. This result indicates that the market was willing to accept potentially contaminated corn only if it came at a significant price discount.

The effects of the StarLink contamination extend well beyond the corn market. The StarLink case continues to surface around the world as an example of policy error in managing biotechnology adoption. Such use of the StarLink incident as a reason to restrict the propagation of GM crops will increase the future costs of developing and marketing biotech crops. The European Union points to the StarLink incident as evidence that GM crops cannot be properly segregated from non-GM crops. In responding to a case brought to the World Trade Organization by the U.S. in May 2003, the EU Trade Directorate wrote “The StarLink case is a clear example of the need for appropriate rules for authorization and traceability of GMOs.” In the long run, these indirect negative effects on GM crop adoption may far outweigh the direct effect on corn prices. In retrospect, the U.S. grain handling system was not prepared to handle the split licensing of StarLink.

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Table 1– Testing for StarLink in Japan's Feed Corn Imports

Time Period	Positive Ratio	Commingling Concentration
April 2000 to September 2000	20/30 (66.7 %)	0.51 %
October 2000 to March 2001	34/72 (47.2 %)	0.17 %
April 2001 to September 2001	8/53 (15.0 %)	0.05 %
October 2001 to March 2002	5/45 (11.1 %)	0.09 %
April 2002 to September 2002	4/42 (9.5 %)	0.10 %

Notes: Source is U.S. Embassy, Japan "Update on Japan's Biotechnology Safety Approval and Labeling Policies" GAIN Report #JA3002, February 28, 2003.

Table 2 – Pre-StarLink Cointegration Tests

	Test Statistic	5% Critical Value	Conclusion
Augmented Dickey-Fuller Tests			
Corn	–1.72	–2.86	Unit Root
Sorghum	–1.93	–2.86	Unit Root
Log Relative Price	–4.33	–2.86	Cointegration

Note: The ADF test regressions contained an intercept and two lags. Sample period is Jan 1989 – Dec 1999.

Table 3– Bai-Perron Tests for Breaks in the Cointegrating Relationship

Test	Statistic	5% Critical Value	Date of maximal *F*-statistic	Conclusion
UDmax	148.65	10.17	-	# breaks $\in$ {1,2,3,4,5,6}
WDmax	162.12	10.91	-	# breaks $\in$ {1,2,3,4,5,6}
sup-F(1|0)	148.65	9.63	7/17/00	At least 1 break
sup-F(2|1)	28.57	11.14	12/14/01	At least 2 breaks
sup-F(3|2)	3.49	12.16	2/16/96	2 breaks

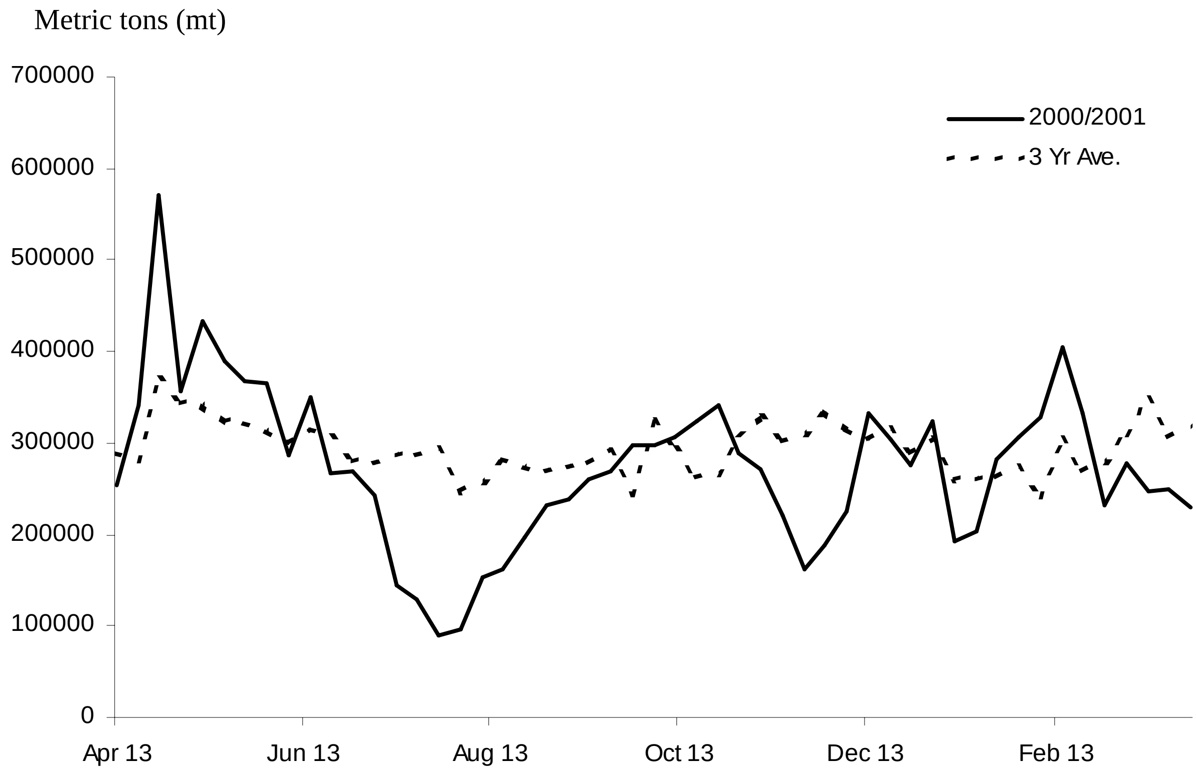
Note: Maximum number of breaks set to six and minimum regime size to 5 percent of sample. Robust standard errors with AR(1) prewhitening used for all tests (Bai and Perron, 1998). Sample period is Jan 1989 – Aug 2002.

Table 4– Pre-StarLink Error Correction Mechanism Estimates

Parameter	Corn	Sorghum
μ	–0.09 (0.01)	
α	–0.024 (0.005)	–0.005 (0.005)
γ_1	0.040 (0.024)	0.294 (0.027)
γ_2	–0.002 (0.025)	0.096 (0.027)
δ_1	–0.003 (0.022)	–0.298 (0.025)
δ_2	0.001 (0.022)	–0.102 (0.024)
Diagnostics		
Error Std. Dev.	0.014	0.015
Log-likelihood	16391.960	
Autocorrelation (p-value)	1.710 (0.789)	

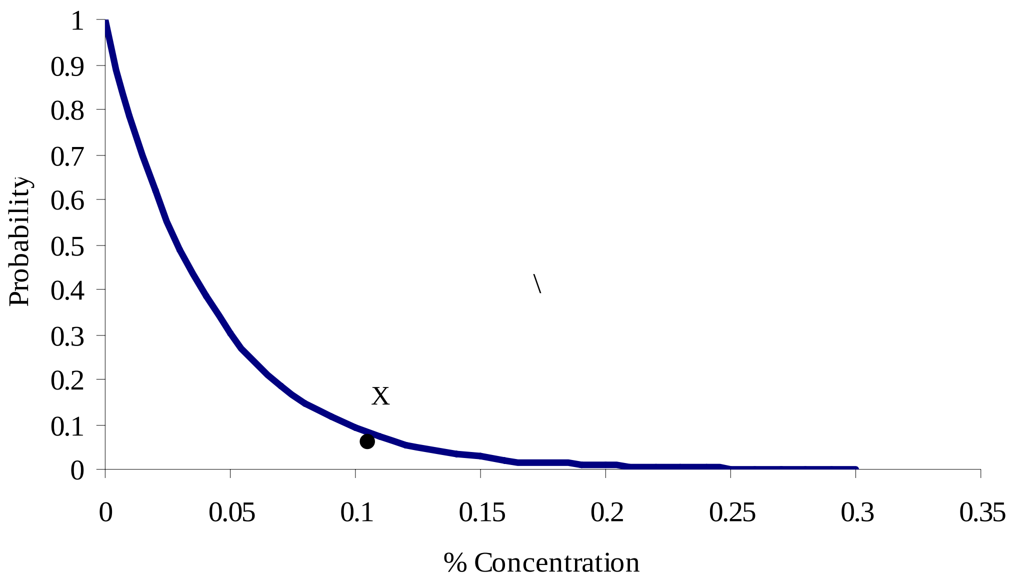
Note: Sample period is Jan 1989–Dec 1999.Estimation by maximum likelihood. Autocorrelation test is LM test for first order serial correlation.

Figure 1. Weekly U.S. Corn Export Sales to Japan



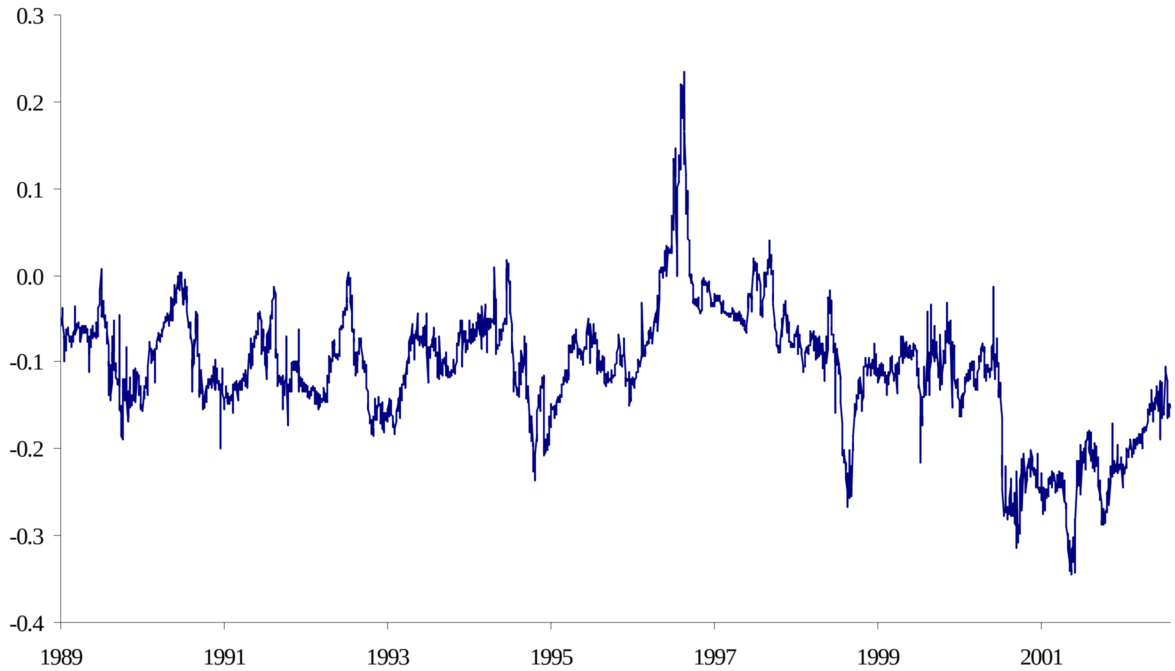
Note: The three-year average is for the three years prior to 2000-2001. The data source is the USDA, FAS.

Figure 2. Probability of Accepting a Cargo of Corn as Non StarLink



Note: Horizontal axis is percent of corn kernels containing Cry9C protein,based on a 2400 kernel sample size. Source: Grain Inspection, Packers, and Stockyards Administration (GIPSA) of USDA, http://www.usda.gov/gipsa/biotech/starlink/cry9cdetection.htm.

Figure 3. Log Relative Price of Corn and Sorghum



Note: The corn series measures mean daily bids in the central Illinois market. The sorghum series measures mean daily bids in the Louisiana Gulf. Prices are measured in cents per bushel.
Source: Commodity Research Bureau.

Figure 4. Forecast Errors During StarLink Event