Spatial Market Integration in the Presence of Threshold Effects*

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Abstract

Threshold cointegration models are used to evaluate spatial price dynamics among regional corn and soybean markets in North Carolina. Thresholds, reflecting the influences of transactions costs, are confirmed and spatial integration is strongly supported. Results indicate that equilibrating adjustments to market shocks are generally complete in two weeks.

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1 Introduction

A huge volume of empirical research has evaluated the extent to which spatially separate markets are integrated. Though the term is used loosely in the literature, tests of 'market integration' usually consider the extent to which shocks are transmitted among spatially separate markets. Integration of markets may have important implications for price discovery and the operation of the market since persistent deviations from integration may imply riskless profit opportunities for spatial traders.

Early studies typically adopted price correlation or regression-based tests. More recent studies have built upon the realization that the price data typically used to evaluate spatial integration are often nonstationary, leading to inferential problems in empirical tests. A variety of econometric procedures appropriate to nonstationary and cointegrated data were adopted and used to evaluate spatial integration (see, for example, Ardeni (1989), Goodwin (1991), and Baffes (1991)).

Regression and cointegration-based tests have recently been criticized for the ignorance of transactions costs (McNew and Fackler (1997), Fackler and Goodwin (1999), Barrett (1996)).[1] The primary mechanism ensuring integration is spatial trade and arbitrage.[2] The presence of transactions costs, which typically are unobservable, may lead to a 'neutral-band' within which prices are not linked to one another.

Recognition of the important but often neglected role of transactions costs has led to the application of new empirical approaches which explicitly recognize the influences of transactions costs on spatial market linkages. Spiller and Wood (1988), Sexton, Kling, and Carman (1991), and Baulch (1997) applied endogenous switching models which account for the multiple regimes that may result from transactions costs. In another line of research, Obstfeld and Taylor (1997) and Goodwin and Grennes (1998) applied threshold autoregression models in a study of market integration. Such models recognize thresholds, caused by transactions costs, that deviations must exceed before pro-

[1] The idea is not new. Heckscher (1916) noted that transactions costs could create 'commodity points'—a neutral band which causes deviations from market integration.

[2] This mechanism may involve explicit arbitrage where traders transport grain between terminal markets in response to price differences. Alternatively, and probably more likely for the markets considered here, integration may result from the actions of a large number of widely dispersed producers who evaluate price conditions among several terminal markets and sell in the market with the highest net price. Such collective actions lead to equalization of net marginal returns across space.

voking equilibrating price adjustments which lead to market integration. Threshold effects occur when larger shocks (i.e., shocks above some threshold) bring about a different response than do smaller shocks. The resulting dynamic responses may be of a nonlinear nature in that they may involve various combinations of adjustments from alternative regimes defined by the thresholds.

The objective of this analysis is to evaluate price linkages among several local corn and soybean markets in North Carolina. Our approach explicitly accounts for the 'neutral band' resulting from transactions costs which may inhibit market integration. We utilize the threshold cointegration methods recently introduced by Balke and Fomby (1997). In particular, a multiple-threshold error correction model allowing asymmetric adjustments is estimated and used to evaluate the dynamic time paths of price adjustments in response to spatially isolated shocks in each of the markets. We utilize a large sample of daily prices quoted at the four principal corn and soybean markets over a seven year period.

2 Econometric Methods

Tong (1978) originally introduced nonlinear threshold time series models. Tsay (1989) developed techniques for testing autoregressive models for threshold effects and modeling threshold autoregressive processes. Balke and Fomby (1997), noting the correspondence between error correction models representing cointegration relationships and autoregressive models of an error correction term, extended the threshold autoregressive models to a cointegration framework. Balke and Fomby (1997) also showed that standard methods for evaluating unit roots and cointegration work reasonably well when threshold cointegration is present.[3]

Consider a standard cointegration relationship representing an economic equilibrium

$$y_{1t} - \beta_1 y_{2t} - \beta_2 y_{3t} - \ldots \beta_k y_{kt} = \nu_t, \quad \text{where} \quad \nu_t = \rho \nu_{t-1} + e_t. \tag{1}$$

Cointegration of the y_{it} variables depends upon the nature of the autoregressive process for ν_t. As ρ approaches one, deviations from the equilibrium become nonstationary and thus the y_{it} variables are not cointegrated. Balke and Fomby (1997) extend this simple framework to the case where ν_t

[3]Balke and Fomby (1997) and Enders and Granger (1998) have also shown, however, that standard tests may lack power in the presence of asymmetric adjustment.

follows a threshold autoregression:

$$\rho = \begin{cases} \rho^{(1)} & \text{if} \quad |\nu_{t-1}| \leq c \\ \rho^{(2)} & \text{if} \quad |\nu_{t-1}| > c, \end{cases} \tag{2}$$

where c represents the threshold which delineates alternative regimes.[4] A common case is that of $\rho^{(1)} = 1$, which implies that the relationship for small deviations from equilibrium is characterized by a random walk (i.e., a lack of cointegration). Parity relationships among commodity prices and interest rates have been examined in such a context.[5]

An equivalent vector error correction representation of the threshold model can be written as:

$$\Delta y_t = \begin{cases} \sum_{i=1}^{p} \gamma_i^{(1)} \Delta y_{t-i} + \theta^{(1)} \nu_{t-1} & \text{if} \quad |\nu_{t-1}| \leq c \\ \sum_{i=1}^{q} \gamma_i^{(2)} \Delta y_{t-i} + \theta^{(2)} \nu_{t-1} & \text{if} \quad |\nu_{t-1}| > c. \end{cases} \tag{3}$$

Balke and Fomby (1997) discuss a number of extensions to this framework, including models with multiple thresholds which imply multiple parametric regimes and thus allow asymmetric adjustment.[6] In our analysis, we follow Martens, Kofman, and Vorst (1998) and utilize two thresholds (c_1 and c_2) which allows three regimes and thus permits asymmetric adjustment.[7]

Testing for threshold effects presents a number of challenges. Tsay (1989) developed a general nonparametric test for the nonlinearity implied by thresholds in an autoregressive series. Consider a standard autoregressive model of the form:

$$\nu_t = \alpha + \gamma \nu_{t-1} + \epsilon_t. \tag{4}$$

In constructing Tsay's (1989) test, we denote each combination of ν_t and ν_{t-1} as a 'case' of data. The individual cases of data are ordered according to the variable relevant to the threshold behavior, ν_{t-1} in this case. Recursive residuals are obtained by estimating the autoregressive model for an initial sample and then for sequentially updated samples obtained by adding a single observation. A test of nonlinearity is then given by the regression F-statistic obtained by regressing the recursive residuals on the explanatory variables (ν_{t-1}). Obstfeld and Taylor (1997) note that, as a practical matter, the

[4]More generally, thresholds pertain to some delay parameter d in adjustment to ν_t, such that $|\nu_{t-d}| \leq c$ defines the threshold. Although testing for d is discussed below, most applications assume a delay of $d = 1$.

[5]See Obstfeld and Taylor (1997) and Goodwin and Grennes (1998) for examples of the former and Siklos and Granger (1997) for an example of the latter.

[6]In the case of k thresholds, $k + 1$ different regimes are implied, each of which may imply its own set of dynamics for the system. Extensions to this framework include 'band-TAR' models in which adjustment is toward the edge of the threshold and 'returning-drift' TAR models which model the processes as random walks with drift toward the thresholds.

[7]The number of thresholds considered is typically constrained by the number of available observations, 1773 in our case.

test should be run with both increasing and decreasing ordering in the arranged autoregression.[8] Tsay's (1989) test is also useful in determining the 'delay' parameter d which defines the threshold autoregression in equation (2). The test is typically run for alternative delays and the delay giving the largest F statistic is chosen as optimal.

Once the presence of threshold effects is confirmed, some parametric estimation strategy must be considered to estimate the threshold. Following the standard approach, we utilize a two-dimensional grid search to estimate the thresholds c_1 and c_2 which define the three regimes. Two alternative grid search techniques have been proposed. Obstfeld and Taylor (1997) use a grid search to find the threshold which maximizes a likelihood function. Alternatively, we follow Balke and Fomby (1997) and use a grid search which minimizes a sum of squared error criterion.

Our specific estimation strategy can be summarized as follows. First, standard Dickey-Fuller unit root tests and Johansen cointegration tests are used to evaluate the time-series properties of the data. We then follow the general two-step approach of Engle and Granger (1987) and consider ordinary least squares estimates of a cointegrating relationship among the variables.[9] Lagged residuals from this regression are then used to define the error correction terms. A two-dimensional grid search is then conducted to define two thresholds. In particular, we search for the first threshold between 1% and 99% of the largest (in absolute value) negative error correction term. In like fashion, we search for the second threshold between 1% and 99% of the largest positive error correction term. The error correction model is then estimated conditional on the threshold parameters.

A test of the statistical significance of the differences in parameters across alternative regimes is desirable. A standard test of parameter differences across regimes is equivalent to a conventional Chow test. As is well known, this testing problem is complicated by the fact that the threshold parameter is not identified under the null hypothesis of no threshold effects and thus conventional test statistics have nonstandard distributions.[10] Hansen (1997) has developed an approach to test-

[8]Additional lags of the error-correction term may be added to produce white noise residuals. The test is nonparametric in that it depends neither on the number of thresholds or their values. The alternative ordering of the data in the arranged regressions allows more power in discerning thresholds for which data are concentrated in a particular regime at either end of the arranged series. We report only the more significant of the two ordered tests.

[9]In that the cointegrating relationship represents an equilibrium where $\alpha = 0$ and $\beta = 1$ is expected, we consider using price differentials as well as residuals from the cointegrating regression as error correction terms. As always, when residuals are used, the results may be sensitive to the normalization rule.

[10]Our grid search using the SSE criteria is equivalent to a sup-Wald Chow test approach, where the largest test statistic (i.e., smallest SSE) is used to define a break.

ing the statistical significance of threshold effects. After optimal thresholds have been identified, a conventional Chow-type test of the significance of threshold effects (i.e., the significance of the differences in parameters over alternative regimes) is conducted. Because the test statistic has a nonstandard distribution, simulation methods are used to approximate the asymptotic null distribution and identify appropriate critical values. Hansen (1997) recommends running a number of simulations whereby the dependent variables are replaced by standard normal random draws. For each simulated sample, the grid search is used to select optimal thresholds and the standard Chow-type test is used to test the significance of the threshold effects. From this simulated sample of test statistics, the asymptotic p-value is approximated by taking the percentage of test statistics for which the test taken from the estimation sample exceeds the observed test statistics.

3 Empirical Application

Our application is to daily corn and soybean prices observed at four important North Carolina terminal markets. In the case of corn, prices were quoted at Williamston, Candor, Coefield, and Kinston. For soybeans, prices were quoted at Fayetteville, Raleigh, Greenville, and Kinston. In each case, the largest markets (Williamston for corn and Fayetteville for soybeans) were taken as the central market against which the remaining three markets were compared. Our evaluations are of a pair-wise nature; we compare prices in each market to the central market price. The prices were observed continuously between January 2, 1992 and March 4, 1999. A small number of price quotes were missing in each of the markets. On days where prices were missing in every market (typically holidays), the observations were omitted and a smooth continuity of prices was assumed. The remaining missing observations were replaced using cubic spline interpolation.[11]

The empirical analysis is based upon logarithmic transformations of the prices. Standard unit-root tests confirmed a single unit root in each series. Ordinary least squares estimates of the cointegrating relationships are presented in Table 1. In all but one case, the intercept terms are close to zero and the slope parameters are very near to one. In light of the OLS estimates, we assume that $\alpha = 0$ and $\beta = 1$ in constructing error correction terms in order to facilitate interpretation of the results in terms of price differentials.[12]

[11] The percentage of observations missing varied from 0.5% to 1.6% of the total sample.

[12] This restriction is standard in analyses of parity conditions (see, for example, Obstfeld and Taylor (1997) and

Johansen (1988) cointegration tests (Table 1) indicated the existence of a single cointegrating relationship among each of the pairs of prices.[13] Lag orders for the cointegration tests and threshold error correction models were chosen using and Schwartz-Bayesian criteria and by considering autocorrelation among residuals. The alternative criteria indicated lag orders ranging from 2 to 6 days. Confirmation of cointegration, in spite of the many weaknesses of such tests (Fackler and McNew (1997)), does indicate the existence of stable long run equilibria among the prices and thus is consistent with integration.

We utilized the maximum likelihood testing procedures of Johansen and Juselius (1992) to make inferences about the cointegrating vector implicit in the Johansen (1988) estimates. Though, as is reflected in Table 1, the estimates were very close to the hypothesized values, the large number of observations and resulting low standard errors resulted in large likelihood ratio test statistics (Tables 2 and 3), thus rejecting the null hypothesis that $\alpha = 0$ and $\beta = 1$.

Tsay's (1989) test was conducted using the error correction terms implied by the price differentials. Results for corn are presented in Table 2 and results for soybeans are presented in Table 3. In every case, the test strongly rejects linearity and thus implies the presence of one or more thresholds in the autoregressive models of the error correction terms. Two dimensional grid searches were used to identify the sum of squared error minimizing thresholds. These thresholds (Tables 2 and 3) are generally symmetric about zero. The thresholds vary across markets considerably, being highest in the case of the Coefield-Williamston corn market linkage and the Kinston-Fayetteville soybean market linkage. As would be expected, in most cases the thresholds indicate that the distribution of price differences is heavily skewed toward one side of zero. This reflects a typical basis differential where one market's prices are usually above (or below) another market's prices. In every case, the central market, against which comparisons are made, typically has a lower price. Outlying markets have higher prices, reflecting the transportation costs associated with moving corn and soybeans toward the central (higher volume) markets. Only in the case of the Candor-Williamston corn market linkage do we see a significant concentration of price differences (i.e., error correction terms) in the regime defined by the lower threshold. This market is the most distant from Williamston and thus may draw producers' product from a different geographic region.

Martens, Kofman, and Vorst (1998)).

[13] In that deterministic time trends did not appear to be present in the series, we restricted the intercept term to apply to the cointegration relationship only.

The statistical significance of the threshold effects was also evaluated using Hansen's (1997) testing approach. Standard Chow-type chi-square tests of parameter differences across regimes were considered. In every case, the test statistics were large, significantly exceeding standard chi-square critical values. In that the test statistics are conditioned upon the thresholds which were chosen in a preceding grid search, the statistics do not have standard chi-square distributions. Following Hansen (1997), we simulated critical values using 200 replications and a modified grid search.[14] In every case, the test statistic exceeded all of the 200 replications simulated under the null hypothesis.

Parameter estimates (not presented here) indicated significant dynamic relationships among the price series. Error correction terms were especially significant, confirming the cointegrated nature of the price series.

Interpretation of the dynamic interrelationships among prices at alternative markets is best pursued through a consideration of impulse response functions. Again, in contrast to the linear model case, the response to a shock is dependent upon the history of the series. In addition, the possibly asymmetric nature of responses implies that the size and sign of the shock will influence the nature of the response. In this light, there are many different possible impulse response functions. We chose a single observation (observation 1000, corresponding to January 9, 1996) to evaluate responses to one-half standard deviation shocks. We adopt the nonlinear impulse response function approach of Potter (1995), which defines responses (denoted I_{t+k}) on the basis of observed data $(z_t, z_{t-1}, \ldots)$ and a shock (υ) as:

$$\begin{aligned} I_{t+k}(\upsilon, Z_t, Z_{t-1}, \ldots) &= E[Z_{t+k} | Z_t = z_t + \upsilon, Z_{t-1} = z_{t-1}, \ldots] \\ &- E[Z_{t+k} | Z_t = z_t, Z_{t-1} = z_{t-1}, \ldots]. \end{aligned} \tag{5}$$

It should also be noted that, in light of the nonstationary nature of the price data and the error correction properties of the system of equations, shocks may elicit either transitory or permanent responses. In particular, nonstationarity implies that shocks may permanently alter the time path of variables.

Figure 1 illustrates responses to one-half standard deviation positive and negative shocks in each of the markets. The first three rows illustrate responses to shocks in corn markets while

[14] The number of replications was necessarily limited by the long computing time. The grid search was modified by searching for each threshold conditional upon the other. This was repeated, alternating between each threshold, until estimates converged. A comparison to the full two-dimensional grid search revealed identical threshold estimates.

the latter three rows illustrate responses to shocks in soybean markets. In most cases, the shocks result in permanent shifts in the price series, reflecting the nonstationary nature of the price data. The responses suggest that, after some short run dynamic adjustments, the prices converge to one another over the long run (i.e., generally after 7 days following the shock). Evidence of asymmetries in price adjustments is limited. In most cases the responses to negative shocks, though naturally of an opposite sign, are quite similar to the corresponding responses to positive shocks.

Perhaps most important for market integration is the finding that prices quickly converge following an isolated, exogenous shock to one of the price series. Although the prices may not converge toward absolute equality for many periods, the impulses do reflect behavior consistent with price convergence. It should be noted that one-half standard deviation shocks are relatively large and are not likely to be observed in day to day price movements. Responses to very small shocks (i.e., shocks that are not large enough to push the price differential outside of the neutral band between the thresholds) resulted in much different responses. In many cases, these responses were not consistent with stable price adjustments. Correlation between prices within the neutral band may be largely of a spurious nature and thus may not imply equilibrating behavior.

In all, the impulse responses are generally in agreement with expectations and provide strong support for integrated markets. Responses to market shocks are generally complete after 15 days. Responses are generally as one would expect, with positive shocks eliciting positive responses and negative shocks eliciting negative responses.

4 Concluding Remarks

We have evaluated spatial price linkages and daily price dynamics among regional corn and soybean markets in North Carolina utilizing asymmetric, threshold error correction models. Our results confirm that such markets are tightly integrated. Our analysis confirms the significance of threshold effects and suggests that their presence may significantly influence spatial price linkages. We utilize nonlinear impulse response functions to evaluate the dynamic paths of adjustment to exogenous, localized shocks. The responses confirm equilibrating responses consistent with price equalization and integration of markets. Adjustments are generally complete after 15 days. Though modest asymmetries are revealed, positive and negative shocks generally yield symmetric responses.

Table 1. OLS Estimates of Cointegrating Relationship: $P_t^1 = \alpha + \beta P_t^2$

Markets	α	β	R^2
Corn:			
Candor-	0.1750	0.9018	0.980
Williamston	(0.0031)[a]	(0.0031)	
Corn:			
Coefield-	0.0460	0.9911	0.974
Williamston	(0.0040)	(0.0039)	
Corn:			
Kinston-	0.0159	0.9965	0.998
Williamston	(0.0011)	(0.0011)	
Soybeans:			
Raleigh-	−0.0240	1.0119	0.998
Fayetteville	(0.0019)	(0.0010)	
Soybeans:			
Greenville-	−0.0381	1.0004	0.988
Fayetteville	(0.0049)	(0.0026)	
Soybeans:			
Kinston-	−0.0445	1.0033	0.987
Fayetteville	(0.0051)	(0.0027)	

[a]Numbers in parentheses are standard errors.

Table 2. Cointegration and Threshold Testing Results: Corn

Markets	Test	Test Statistic[a]
Corn: Candor-Williamston	Max. Eigen Value Test: r=0	36.09**
	Trace Test: r=0	37.9**
	Max Eigen Value and Trace Test: r=1	1.81
	ADF Test of Nonstationary Differential	−3.95**
	LR Test of $\alpha = 0, \beta = 1$	33.12**
	Regime I (No. Obs.)	$-\infty < \nu_{t-1} \leq -0.0255$ (295)
	Regime II (No. Obs.)	$-0.0255 < \nu_{t-1} \leq 0.0073$ (716)
	Regime III (No. Obs.)	$0.0073 < \nu_{t-1} < \infty$ (761)
	Tsay's Nonlinearity Test	4.09**
	Hansen's Threshold Test	77.54**
Corn: Coefield-Williamston	Max. Eigen Value Test: r=0	45.50**
	Trace Test: r=0	47.73**
	Max Eigen Value and Trace Test: r=1	2.23
	ADF Test of Nonstationary Differential	−5.17**
	LR Test of $\alpha = 0, \beta = 1$	27.54**
	Regime I (No. Obs.)	$-\infty < \nu_{t-1} \leq -0.0572$ (69)
	Regime II (No. Obs.)	$-0.0572 < \nu_{t-1} \leq 0.0675$ (6)
	Regime III (No. Obs.)	$0.0675 < \nu_{t-1} < \infty$ (1697)
	Tsay's Nonlinearity Test	11.97**
	Hansen's Threshold Test	50.36**
Corn: Kinston-Williamston	Max. Eigen Value Test: r=0	12.63*
	Trace Test: r=0	14.44
	Max Eigen Value and Trace Test: r=1	1.81
	ADF Test of Nonstationary Differential	−2.07
	LR Test of $\alpha = 0, \beta = 1$	8.96**
	Regime I (No. Obs.)	$-\infty < \nu_{t-1} \leq -0.0125$ (248)
	Regime II (No. Obs.)	$-0.0125 < \nu_{t-1} \leq 0.0188$ (24)
	Regime III (No. Obs.)	$0.0188 < \nu_{t-1} < \infty$ (1500)
	Tsay's Nonlinearity Test	3.19*
	Hansen's Threshold Test	86.25**

[a]Single and double asterisks indicate statistical significance at the $\alpha = .10$ and $\alpha = .05$ levels, respectively. Critical values for cointegration tests taken from Johansen and Nielsen (1993).

Table 3. Cointegration and Threshold Testing Results: Soybeans

Markets	Test	Test Statistic[a]
Soybeans:	Max. Eigen Value Test: r=0	49.35**
Raleigh-	Trace Test: r=0	51.42**
Fayetteville	Max Eigen Value and Trace Test: r=1	2.08
	ADF Test of Nonstationary Differential	−4.58**
	LR Test of $\alpha = 0, \beta = 1$	9.2**
	Regime I (No. Obs.)	$-\infty < \nu_{t-1} \leq -0.0060$ (166)
	Regime II (No. Obs.)	$-0.0060 < \nu_{t-1} \leq 0.0103$ (47)
	Regime III (No. Obs.)	$0.0103 < \nu_{t-1} < \infty$ (1559)
	Tsay's Nonlinearity Test	14.27**
	Hansen's Threshold Test	62.28**
Soybeans:	Max. Eigen Value Test: r=0	28.51**
Greenville-	Trace Test: r=0	33.09**
Fayetteville	Max Eigen Value and Trace Test: r=1	1.96
	ADF Test of Nonstationary Differential	−3.52**
	LR Test of $\alpha = 0, \beta = 1$	25.18**
	Regime I (No. Obs.)	$-\infty < \nu_{t-1} \leq -0.0102$ (410)
	Regime II (No. Obs.)	$-0.0102 < \nu_{t-1} \leq 0.0239$ (20)
	Regime III (No. Obs.)	$0.0239 < \nu_{t-1} < \infty$ (1342)
	Tsay's Nonlinearity Test	4.43**
	Hansen's Threshold Test	62.42**
Soybeans:	Max. Eigen Value Test: r=0	31.14**
Kinston-	Trace Test: r=0	33.09**
Fayetteville	Max Eigen Value and Trace Test: r=1	1.96
	ADF Test of Nonstationary Differential	−3.43**
	LR Test of $\alpha = 0, \beta = 1$	27.49**
	Regime I (No. Obs.)	$-\infty < \nu_{t-1} \leq -0.0888$ (9)
	Regime II (No. Obs.)	$-0.0888 < \nu_{t-1} \leq 0.0222$ (65)
	Regime III (No. Obs.)	$0.0222 < \nu_{t-1} < \infty$ (1698)
	Tsay's Nonlinearity Test	12.82**
	Hansen's Threshold Test	63.73**

[a]Single and double asterisks indicate statistical significance at the $\alpha = .10$ and $\alpha = .05$ levels, respectively. Critical values for cointegration tests taken from Johansen and Nielsen (1993).

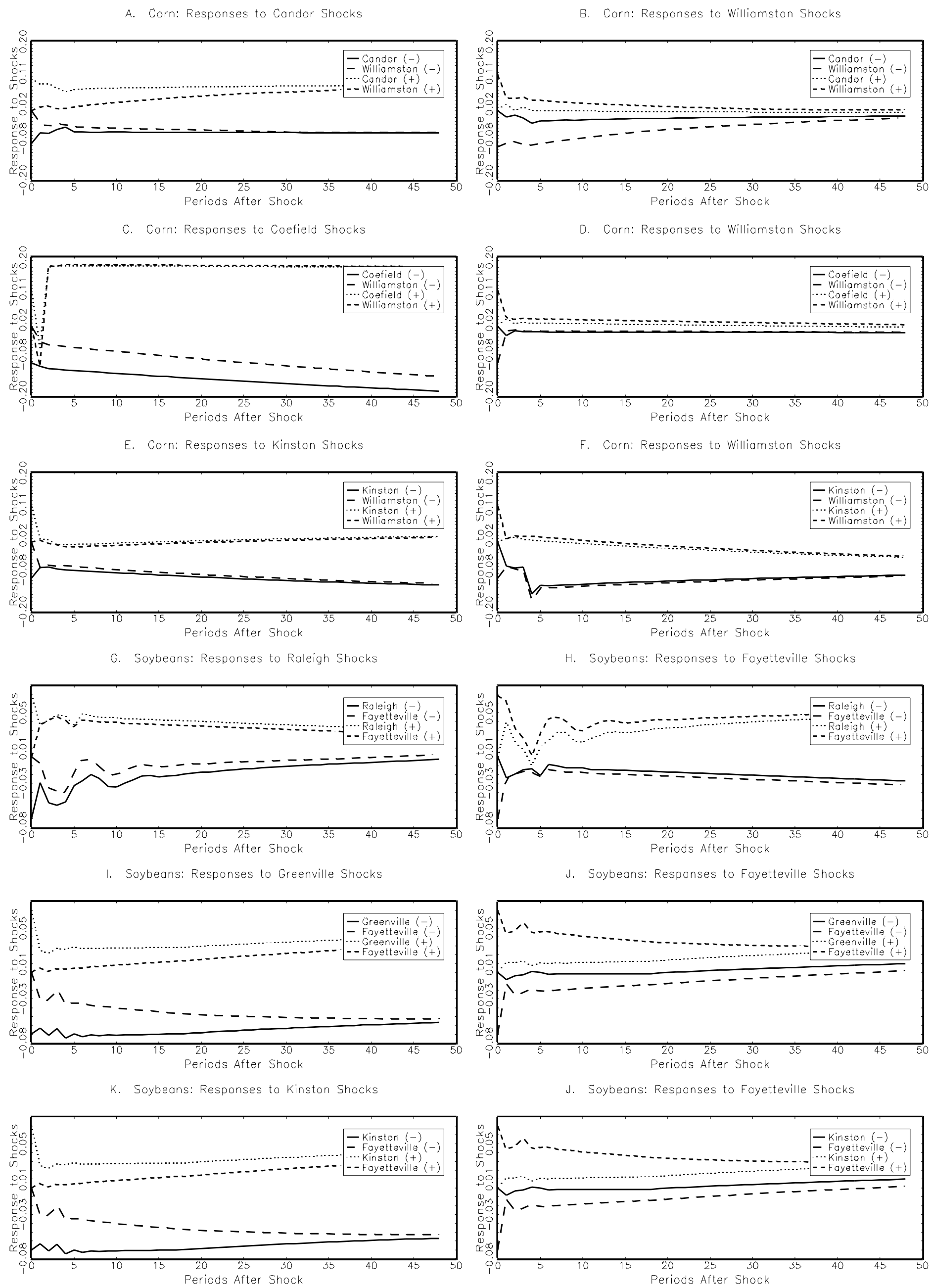

Figure 1: Nonlinear Impulse Response Functions

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