The Influence of Transportation Rates on Grain Prices: A Dynamic Analysis

Tun-Hsiang (Edward) Yu
Center for Agricultural and Rural Development
Iowa State University
Ames, IA 50011-1070
Tel: (515) 294-8015
Fax: (515) 294-6336
E-mail: edyucard@iastate.edu

David A. Bessler
Department of Agricultural Economics
Texas A&M University
College Station, TX 77843
Tel: (979) 845-3096
Fax: (979) 845-1563
E-mail: d-bessler@tamu.edu

Stephen W. Fuller
Department of Agricultural Economics
Texas A&M University
College Station, TX 77843
Tel: (979) 845-1941
Fax: (979) 845-6378
E-mail: sfuller@tamu.edu

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Abstract

An efficient and reliable transportation system is important to the marketing of U.S. grain since transport costs often account for a significant portion of the grain price in destination markets. Changes in a mode's transportation rate may divert the grain flow and ultimately influence prices in origin and destination markets. The objective of this paper is to explore the impact of transport rates on grain prices using a multi-destination, inter-temporal approach, which can better capture the dynamic influence of transportation rates on grain prices. Corn prices at two major port areas and selected domestic markets are included in the analyses as are barge rates on the Upper Mississippi and Illinois Rivers, rail rates linking selected production regions and domestic markets, and ocean rates linking the export ports to foreign markets. A multivariate time-series analysis and graphical models are employed to analyze monthly prices and transport rate series extending from January 1990 to December 2002. Results show barge and ocean rates influence corn prices in contemporaneous time and, in the longer-run, perturbations in ocean freight rates have the greatest influence on corn prices while shocks in barge rates account for a more modest 12 percent of variation in these prices. The rail rate linking the north central U.S. to the Pacific Northwest port area initially has a modest impact on corn price, however, over an extended time horizon its influence increases to account for about 12 percent of the variation in these prices. Perturbations in all transport rates (barge, rail, and ocean) account for 40-65 percent of the variation in domestic and export corn prices.

The Influence of Transportation Rates on Grain Prices: A Dynamic Analysis

The United States produces numerous agricultural products to meet the demand of the nation as well as the rest of the world. Clearly, an efficient and reliable transportation system is important to the marketing of those agricultural commodities. It is especially true for field crops since the dominant production regions for major crops, such as corn, soybeans and wheat, are primarily located in the north central U.S., which is over a thousand miles from many domestic markets and the principal export ports. Currently, most of the export-bound grain is shipped from the Mississippi Gulf, which handles about 60 percent of the U.S grain outflow, and the Pacific Northwest (PNW) ports. The primary transportation arteries linking the north central production region to the Gulf ports are the Upper Mississippi and Illinois Rivers; while railroads are the bridge connecting the Midwest with the PNW ports. In addition to export markets, grain companies in the north central U.S. ship grain to domestic markets for feed or industrial use via rail or truck since domestic demand accounts for a large fraction of total U.S. grain disappearance. The choice of a destination market by a shipper and associated shipping route depends largely on grain prices in that market and the rates of involved transportation modes in accessing the market. Accordingly, the interaction between transportation rates and grain prices is expected since transport rates often account for a significant portion of the grain price. Changes in the rate of a particular transportation mode may divert the grain flow and ultimately influence origin and destination market prices.

Earlier studies have examined the effect of transportation rates/fees (barge, rail or truck) on grain prices and flow (Babcock and German, 1983; Fuller, Makus, and Taylor, 1983; Fellin and Fuller, 1997; Hauser, Beaulier, and Baumel, 1985). These studies provided considerable information and knowledge of grain transportation and agricultural markets; however, none of these studies have examined the influence of transport rates on grain prices in a dynamic framework. Recent spatial market integration studies have adopted time-series analysis to evaluate the role of transport rates on the grain price discovery process in the long-run. Examples can be found in Goodwin and Schroeder (1991); Haigh and Holt (2000); Haigh and Bryant (2001); Haigh and Bessler (2004); and McKenzie (2005). Although these studies took into account the dynamic effect of transport rates on grain price volatility and discovery analysis, they usually ignored substitute markets, shipping routes and transportations modes, thus they failed to offer a comprehensive view of the interaction among grain prices and transportation rates. The objective of this paper is to explore the impact of transport costs on grain prices using a multi-market, inter-temporal approach, which can better capture the dynamic influence of transportation rates on grain prices. The dynamics among grain prices at the primary export ports and selected domestic markets, and barge rates on the Upper Mississippi and Illinois Rivers, and other transportation rates linking production regions to destination markets are examined.

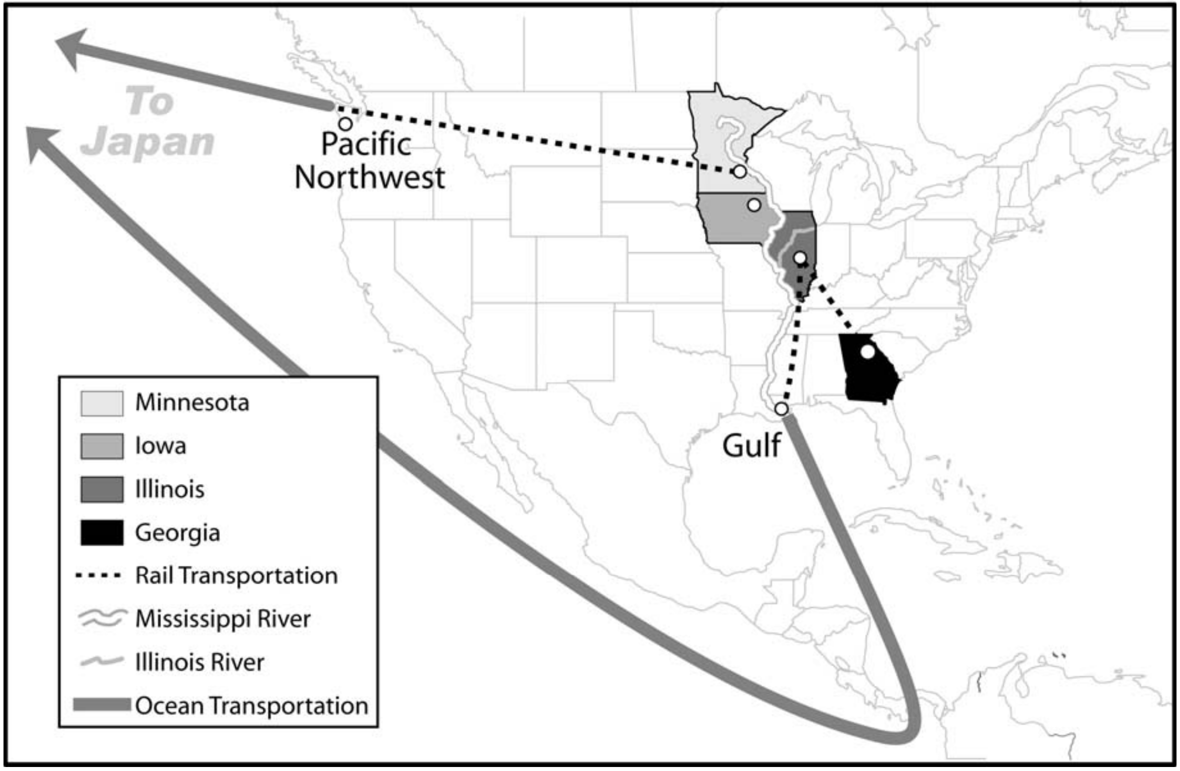
The remainder of the paper is structured as follows: The second section presents the scope of this study. Method of analysis in this paper is discussed in the third section. Data and variables are presented in the fourth section, while section five discusses empirical results. Finally, discussion and conclusions are offered.

SCOPE OF STUDY

In order to obtain a more comprehensive understanding regarding the influence of transport rates on a grain market price, we examine both export and domestic grain markets. Two primary port regions, the Mississippi Gulf and the PNW, are included. More than 80 percent of the U.S. export-grain shipments departed through these two port areas in 2004 (USDA/AMS, 2005). Grain prices at these two ports represent a proxy for the-rest-of-the-world's demand for U.S. grain. For domestic markets, Iowa, Illinois and Minnesota are included in the study because these north central states are important corn and soybean production and processing regions (USDA/NASS, 2005). In addition, an important grain-deficit region, the southeast U.S, is considered. The Georgia grain market is chosen as a proxy for this region's demand.

Transportation rates that link the north central U.S. to Mississippi Gulf ports are included, in particular, barge transportation on the Upper Mississippi and Illinois Rivers and railroad rates linking Illinois to the Mississippi Gulf are featured. These are critical arteries for transporting grain from the hinterland to the Mississippi Gulf port area. Also included are railroads that link the north central U.S. (e.g., Minnesota) to the PNW ports: they represent an alternate route to the international grain market. In addition, railroads linking Illinois to Georgia are included because of the importance of this transportation corridor. Ocean transportation is the primary means of connecting U.S. grain to the world market. Ocean shipping rates linking the PNW and Mississippi Gulf to Japan are included in this analysis since Asia is the major consumer of U.S. grains. Figure 1 offers geographic insight on these markets and associated shipping routes. These selected markets (except for Georgia market), shipping routes, and transportation modes, represent the typical channel for export-destined grain moving to Asian markets.

Figure 1. Spatial Arrangement of Analyzed Corn Prices and Freight Rates



METHOD OF ANALYSIS

To capture the dynamic interdependence between markets, a time-series mechanism is applied to aggregated, time-series data on grain prices at selected domestic and export markets, and freight rates for barge, railroad, and maritime transport. Additionally, a graphical modeling analysis, directed acyclic graphs (DAGs), is employed to determine the contemporaneous relationships among these markets.

Multivariate Cointegration Analysis

Generally, vector autoregressive (VAR) models are the selected tools for analyzing a set of interrelated variables. A VAR model with *n* lags of M variables is written:

$$(1) \qquad Y_t = \sum_{i=1}^{n} \Gamma_i Y_{t-i} + \mu + e_t (t = 1,...,T)$$

where *Y* is a (Mx1) vector of series at time t, Γ_i a (MxM) matrix of coefficients relating series changes at lagged *i* period to current changes in series, μ is a (Mx1) vector of constant, and ε_t is a (Mx1) vector of innovations. Equation (1) indicates that each of the M variables is a function of *n* lags of all M variables, including itself, a constant and a present innovation (error) term. If some series in the set of evaluated variables are non-stationary and cointegrated, the error correction model (ECM), developed by Johansen (Johansen, 1988, 1991; Johansen and Juselius, 1990), will be utilized to study both short-run discrepancies and long-run equilibrium. An ECM model is written as follows:

$$(2) \qquad \Delta P_t = \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \Pi P_{t-1} + \mu + e_t (t = 1,...,T)$$

Clearly, equation (2) is a VAR model in first differences plus a lagged-level term. The (P_{t-1}) term is the so-called Error Correction Term and the Π is a (MxM) coefficient matrix containing response information of lagged levels of price/rates to current changes.

The long run, short run and contemporary information in these series can be identified through the parameters in equation (2). The information on long-run relationship between the M variables is summarized in Π. When the rank of Π is a positive number, *r*, and it is less than the number of series, *M*, then $\pi = \alpha\beta'$ where α and β are (*M* x *r*) matrices. The β matrix contains the cointegrating parameters and the matrix α includes the information on the speed of adjustment. Testing hypotheses on β can provide information on long-run structure, while testing hypotheses on α and Γ_i can identify the short-run relationships (Johansen and Juselius, 1994; Johansen, 1995). Furthermore, the contemporaneous structure can be summarized through structural analysis of e_t, as described recently in Bessler and Lee (2002) and Bessler and Yang (2003).

It is recognized that individual coefficients of the standard ECM models are difficult to interpret (Sims, 1980). Under such cases, innovation accounting may be the best description of the dynamic structure (Sims, 1980; Lutkepohl and Reimers, 1992; Swanson and Granger, 1997). We estimated the parameters of equation (1) using the maximum likelihood procedure of Johansen (1992). The error correction model is then converted to a levels VAR through algebraic manipulation of the estimated coefficients. The converted VAR can be inverted to a moving average representation (MAR) and the innovation accounting based on the MAR is then generated to summarize the dynamic impacts of transportation rates on grain prices.

The information on the contemporaneous structure of interdependence may be explored by examining the causal relationship among innovations in contemporaneous time t, across markets based on the variance-covariance matrix of innovations (i.e., residuals) from the ECM (Spirtes, Glymour, and Scheines, 2000; Hoover, 2005). We investigate the use of directed acyclic graphs, a graphical modeling methodology, in providing help for obtaining data-based evidence on ordering in contemporaneous time *t*, assuming the information set on Σ_t is causally sufficient. A Bernanke ordering may be used with the discovered structure from the directed graphs (Bernanke, 1983; Doan, 1992).

Directed Acyclic Graphs

The directed acyclic graphs (DAGs) methodology employed here emanates from the field of artificial intelligence and computer science (Pearl, 2000). A directed graph is a picture representing causal flows among variables that have been suggested by prior study or theory to be related. The basic idea is to represent causal relationships among a set of variables using an arrow graph or picture. Mathematically, directed graphs are designs for representing conditional independence as implied by the recursive product decomposition:

$$(3) \qquad P(y_1, y_2, y_3, \ldots, y_m) = \prod_{i=1}^{m} P(y_i \mid v_i)$$

where *P* is the probability of variables y_1 , y_2 , …, y_m; while v_i, presents a subset of variables with y_i in order ($i = 1, 2, \ldots, m$). Pearl (1986, 1995) illustrated the independence relations given by equation (3) by introducing *d-separation*. When the information is blocked between two vertices (say A and B), those two are *d-separated*. This can be found in three cases: a) condition a mediator is causal chains, say B in the graph A → B → C; b) condition a common cause in a causal forks, say variable Z in the graph X ← Z → Y; or c) *do not* condition on a middle variable, say E or any of its descendents in the graph of D→E←F (descendents are not presented here).

Our analysis is based on causal chains (A→ B→C), causal forks (A←B→C), and causal inverted forks (A→B←C) that imply particular correlation and partial correlation structures between and among the measures A, B, and C (Geiger, Verma, and Pearl). If A, B, and C are related as above as a chain, the unconditional correlation between A and C will be non-zero. However, the conditional correlation between A and C given the information in B will be zero. If the three variables A, B, and C are instead related as an inverted fork (as illustrated above) then the unconditional correlation between A and C will be zero, but the conditional correlation between A and C, given B, will be nonzero. Finally, if the events are related in a causal fork (as above), the unconditional correlation between A and C will be non-zero, but the conditional correlation between A and C given B will be zero.

A greedy equivalence search (GES) algorithm is utilized to identify the contemporaneous structure. A GES algorithm proceeds stepwise using a Bayesian scoring criterion to score all possible causal flows between variables to obtain the "best" DAG. This algorithm is described explicitly in Chickering (2002). The software TETRAD IV is developed to process the GES algorithm and its extensions.

DATA AND VARIABLES

This section offers a brief discussion of variables included in the analyses. The crop selected in this study is corn since it has the greatest transportation demand of all grains and is extensively shipped throughout the U.S. to both export and domestic markets. The price data are monthly averages that extend from 1990 through 2002, thus a total of 156 observations. All corn prices, except the Georgia price, and transportation rates were obtained from the U.S. Department of Agriculture, Agricultural Marketing Service. The state average Georgia corn price was obtained from the U.S. Department of Agriculture, National Agricultural Statistics Service (NASS). The NASS collected the Georgia state average price to October 2001. For our study purpose, we estimated the price from November 2001 to December 2002 using North Carolina corn price along with the seasonal dummy variables. The descriptive statistics and plots for these variables are presented in Table 1 and Figures 2 and 3. Monthly average rail rates linking Illinois to the Mississippi Gulf (RIGF), Minnesota to PNW ports (RMP), and Illinois to Georgia (RIGA) are generated from the annual Carload Waybill Sample (Table 1 and Figure 3). The rail rate to the PNW (RMP) is more than double the rate to Mississippi Gulf port (RIGF) and about $7/ton higher than the Illinois-Georgia rate (RIGA). In addition, the rail rate to the Gulf (RIGF) is considered as competitive to the barge rates linking the study region to the Mississippi Gulf (BR). The average monthly barge rate (BR) is lower than the rail rates (RIGF) while the variation in BR is higher than RIGF (Table 1**).**

The two ocean shipping rates, Gulf to Japan (OGJ) and PNW to Japan (OPJ), are comparable (Figure 3). The Spread variable (SPD) is the difference between the two ocean rates (i.e. SPD = OGJ – OPJ). The spread is generated since the relative rates may impact the pricing of other transportation modes, such as rail and barge, and consequently influence the grain prices in various markets. In this study, we use the ocean rates from Gulf to Japan (OGJ) and the spread in rates (SPD) to measure their influence on grain prices. Truck rates are not included in this study since historical data on truck rates are not publicly available. Due to the extended distance from the north central U.S. to ocean ports and increasing motor carrier costs with distance, truck is not a viable transportation option for shipping grain to export port areas. Truck is typically used for intrastate or regional shipments because of its cost advantage.

Several dummy variables were generated to capture the potential influence of policies and structural changes in the industry over the study period (1990:1-2002:12). Previous studies suggested that farm legislation effects grain markets. Hence, one farm legislation dummy variable was generated for the time period starting 1996:4. In addition to the potential role of farm legislation, there were also notable activities in the rail industry that deserve some attention.

Table 1. Descriptive Statistics for Monthly Corn Prices and Freight Rates, 1990 – 2002

Variables	Mean	S.D.	Min.	Max.	C.V.
Corn Prices ($/ton)					
Pacific Northwest (PNW)	107.47	20.99	75.18	199.70	0.20
Mississippi Gulf (GF)	98.13	20.32	67.34	184.64	0.21
Minneapolis (MN)	83.14	20.22	52.33	172.68	0.24
Northeast Iowa (NEI)	80.95	20.45	49.37	167.75	0.25
South Central Illinois (IL)	85.89	20.54	52.91	172.83	0.24
Georgia (GA)	100.47	19.93	65.69	198.49	0.20
Barge Rate ($/ton)					
South of Peoria (BR)	7.92	2.50	4.04	15.27	0.32
Rail Rates ($/ton)					
IL – Gulf (RIGF)	9.30	1.67	5.68	17.43	0.18
MN – PNW (RMP)	25.76	2.05	20.26	33.46	0.08
IL – Georgia (RIGA)	18.72	3.25	10.90	33.05	0.17
Ocean Freight Rates ($/ton)					
Gulf – Japan (OGJ)	22.79	4.61	12.51	35.47	0.20
PNW – Japan (OPJ)	13.51	2.49	9.22	19.99	0.18
Spread (SPD)[*]	9.28	2.83	0.90	15.95	0.30

[*] SPD = OGJ – OPJ

Figure 2. Plots of Six Monthly Corn Prices, 1990-2002 (See Table 1 for definition of variables)

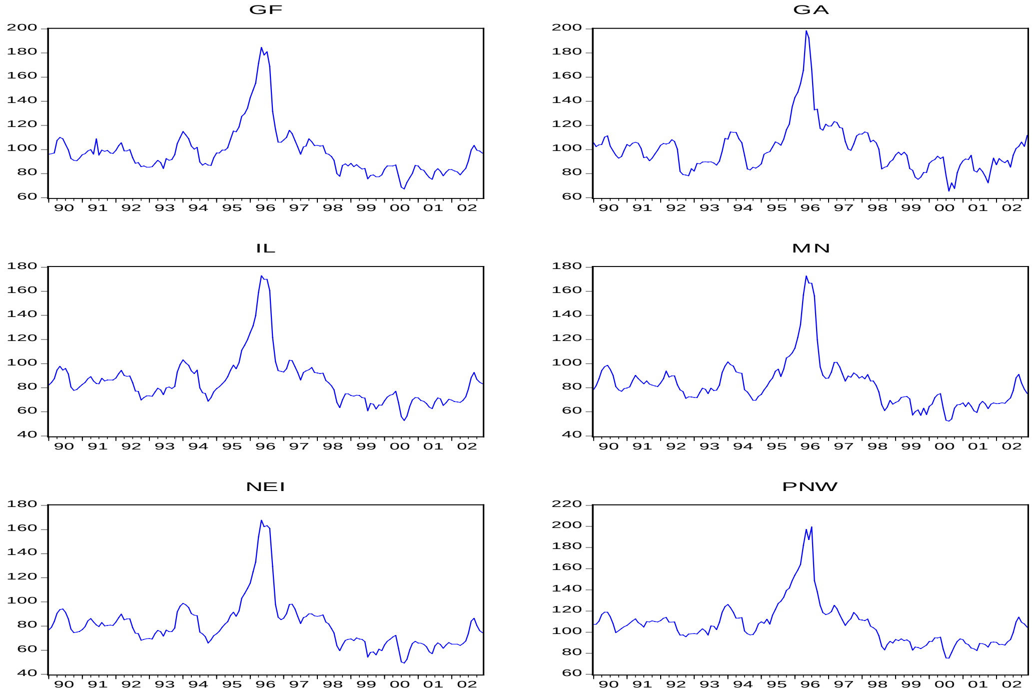
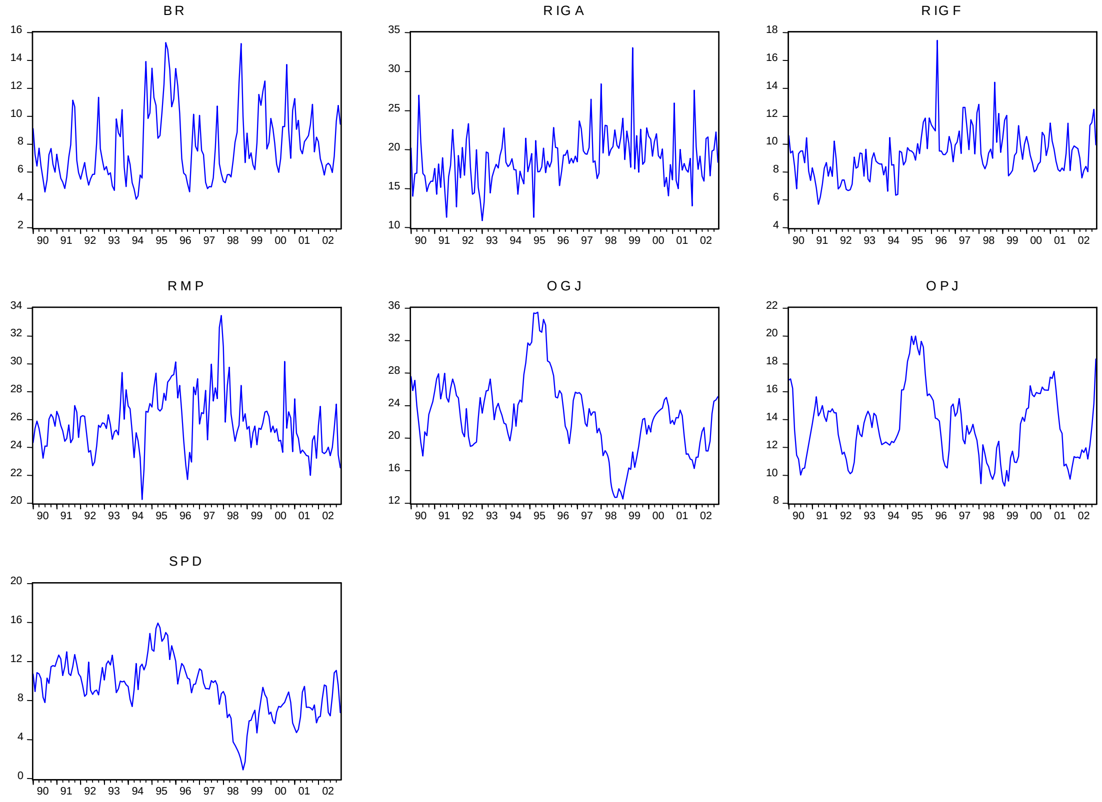


Figure 3. Plots of Monthly Barge, Rail and Ocean Shipping Rates, 1990-2002 (See Table 1 for definition of variables)



There have been numerous mergers among railroad companies during the past twenty years. During this study period, three significant mergers in Class I railroad were exercised. In September 1995, Burlington Northern (BN) and Santa Fe (SF) merged to form BNSF railroad, while Union Pacific (UP) gained control of Southern Pacific (SP) one year later. The third merger occurred in July 1999 when Canadian National Railway (CN) obtained control of Illinois Central, a railroad linking central Illinois to the Mississippi Gulf. Rail companies involved with these mergers ship a significant amount of grain to both export (PNW and the Mississippi Gulf) and domestic markets covered in this study. As a result, the impact of these mergers was considered. Besides the farm legislation and railroad merger dummies, eleven monthly dummies were included to incorporate seasonality.

EMPIRICAL RESULTS

In order to determine if the error correction model (ECM) is appropriate for these data series, unit root tests on the levels of the data are conducted. Results of both Phillips-Perron (1988) and Augmented Dickey-Fuller tests (1981) are presented in Table 2. The null hypothesis of these two tests is that each evaluated series is mean non-stationary. Phillips-Perron tests show the corn prices are non-stationary at the 5 percent significance level since the t-statistics are all greater than the critical value of -2.89. Moreover, all transportation rates, except for two ocean rates (OGJ, SPD) are mean stationary. The Augmented Dickey-Fuller tests offer different perspectives regarding the stationarity of corn prices: Minneapolis (MN), northeast Iowa (NEI), south central Illinois (IL), and Georgia (GA) corn prices are found to be mean stationary. Regardless, both tests show that at least two series of the selected variables are non-stationary, therefore, it is appropriate to conduct a multivariate cointegration analysis (Hansen and Juselius, 1995).

Table 2. Unit Root Tests on Levels of Monthly Corn Prices and Freight Rates

Series	Philips-Perron Test	Augmented Dickey-Fuller Test
PNW	-2.07^{+}	-2.78 (2)$^{+}$
GF	-2.42^{+}	-2.51 (1)$^{+}$
MN	-2.54^{+}	-3.16 (1)
NEI	-2.55^{+}	-3.16 (1)
IL	-2.50^{+}	-2.99 (1)
GA	-2.52^{+}	-2.98 (1)
BR	-5.15	-4.95 (0)
RIGF	-7.64	-6.79 (0)
RMP	-5.92	-5.57 (0)
RIGA	-11.03	-10.51 (0)
OGJ	-2.63^{+}	-2.00 (0)$^{+}$
SPD	-2.61^{+}	-2.63 (0)$^{+}$

Notes: number in parentheses indicate the number of lags of the dependent variable in the augmented Dickey-Fuller test. "$^{+}$" indicates failure to reject the null hypothesis of unit roots for the series.s

The optimal length of lags for a levels VAR model is initially determined prior to further analysis. Table 3 presents Schwarz Loss (1978) and Hannan and Quinn Φ (1970) measures on alternative lag lengths from unrestricted VAR fit to these twelve series (in levels). The measures are fit with eleven monthly indicator variables and one dummy variable associated with farm legislation and three railroad merger dummy variables in each VAR equation to account for deterministic seasonality, policy, and industrial organization impacts. Our search involves lags of zero through six periods. Both measures suggest a VAR of one lag.

Table 3. Loss Metrics on the Order of Lags (k) in a Levels Vector Autoregression on Monthly Corn Prices and Freight Rates

Lag	Schwarz-loss	Hannan and Quinn's Φ
0	23.086	20.739
1	20.115*	16.093*
2	23.189	17.480
3	26.068	18.656
4	29.001	19.870
5	31.417	20.554
6	33.773	21.161

Notes: "*" indicates the optimal length of lag in a levels VAR

Table 4 presents a series of trace tests for cointegration. The table is set up following the sequential testing procedure suggested by Johansen (1992), where we begin testing for zero cointegrating vectors (r = 0) with the constant in the cointegrating space. If we reject this first test, we move on to test r = 0 with the constant outside the cointegrating space. If we reject this hypothesis, we return to tests of r less than or equal to 1, with the constant inside the cointegrating space. We continue until we first fail to reject the null hypothesis. In our case this is indicated in Table 4 by the "#" sign at ten cointegrating vectors with the constant inside the cointegrating space. An alternative approach to determine the rank of the cointegration vector is based on information criteria, which is proposed by Wang and Bessler (2005). Using the Hannan & Quinn Φ statistics, we find eleven cointegration vectors with the constant inside the cointegration space. Since the Monte Carlo study suggested the information criteria method can complement traditional parametric tests (Wang and Bessler, 2005), we decide to select eleven cointegration vectors in this study.

Table 4. Trace Test of Cointegration Among Selected Corn Prices and Freight Rates

R	T*	C(5%)*	D*	T	C(5%)	D
= 0	1137.19	338.10	R	1135.29	323.93	R
≤ 1	885.65	289.71	R	883.79	276.37	R
≤ 2	689.90	244.56	R	688.05	232.60	R
≤ 3	536.95	203.34	R	535.16	192.30	R
≤ 4	411.05	165.73	R	409.26	155.75	R
≤ 5	305.05	132.00	R	303.40	123.04	R
≤ 6	214.62	101.84	R	213.02	93.92	R
≤ 7	144.96	75.74	R	143.36	68.68	R
≤ 8	87.61	53.42	R	86.13	47.21	R
≤ 9	41.80	34.80	R	40.37	29.38	R
≤ 10	17.75	19.99	F #	16.46	15.34	R
≤ 11	1.62	9.13	F	0.40	3.84	F

Given eleven long-run stationary relations are present in the twelve series, it is possible that one or more of the markets are not involved with any of the eleven vectors. Table 5 presents exclusion tests of each series from the cointegration space. The null hypothesis is that each individual series in the system is not in the cointegration space. The test is a distributed chi-squared test with eleven degrees of freedom. The null hypothesis for all prices and rates is rejected in Table 5 since the chi-squared statistic for each is greater than the 5% critical value (19.68). Therefore, all twelve series are in the cointegration space.

Although each series is in the cointegration space, it is possible that some series do not respond to perturbations in the cointegrating space. For instance, if one cointegration vector is out of long-run equilibrium, does market *i* respond to that disequilibria over time? A test of weak exogeneity, presented in Table 6, is used to check this question. The null hypotheses for each row is that series *i* does not respond to perturbations in any of the long run equilibrium (cointegrating vectors). Using a 5% significance level, except for one transportation rate (OGJ), most series appear to restore the long-run equilibrium when new information distracts.

Table 5. Test on Exclusion of Selected Grain Prices and Freight Rates from Cointegration Space

Prices/Rates	Chi-Squared Test	p-value	Decision
PNW	205.14	0.00	R
GF	116.46	0.00	R
MN	117.87	0.00	R
NEI	142.50	0.00	R
IL	107.36	0.00	R
GA	125.92	0.00	R
BR	113.47	0.00	R
RIGF	106.87	0.00	R
RMP	84.32	0.00	R
RIGA	152.38	0.00	R
OGJ	37.30	0.00	R
SPD	44.49	0.00	R

[*] See the definition of the variables in Table 1.

Table 6. Test on Weak Exogeneity of Selected Grain Prices and Freight Rates from Cointegration Space

Prices/Rates	Chi-Squared Test	p-value	Decision
PNW	61.40	0.00	R
GF	104.99	0.00	R
MN	98.32	0.00	R
NEI	108.60	0.00	R
IL	109.78	0.00	R
GA	63.43	0.00	R
BR	26.73	0.00	R
RIGF	92.46	0.00	R
RMP	71.95	0.00	R
RIGA	135.18	0.00	R
OGJ	15.29	0.26	R
SPD	19.83	0.048	R

[*] See the definition of the variables in Table 1.

As discussed earlier, the individual coefficient estimates from the ECM model are difficult to interpret. Therefore, the innovation generated from the ECM is used to study the contemporaneous causal relations. Figure 4 gives the directed acyclic graph derived from the contemporaneous correlation between innovations in each of the twelve prices. Using a GES algorithm, causality flows in contemporaneous time are identified among evaluated grain prices and transportation rates. In Figure 4, barge rates (BR) and three rail rates (RIGA, RMP, RIGF) are exogenous in contemporaneous time. It generally shows that the export markets (GF, PNW) and the southeast domestic markets (GA) affect the corn price in the hinterland (IL, NEI and MN) while the Minneapolis (MN) price is the information "sink". Barge rates (BR) and ocean rates (OGJ) also influence the hinterland price. The graph shows the influence of a price shock on barge and ocean rates will pass through the foreign and domestic corn markets in contemporaneous time (a month in this study); while rail rates do not produce a correspondingly quick impact on corn prices. The corn price at the Mississippi Gulf (GF), Pacific Northwest (PNW) and Georgia (GA) is connected but the causality cannot be determined. Similarly, Gulf price (GF) and ocean rates linking the Gulf and Japan (OGJ) are linked without a confirmed causal relationship. With alternative length of lags and number of cointegration vectors, we find a causal chain from GF to GA through PNW (i.e. GF → PNW → GA) and an information flow from GF to OGJ (GF → OGJ). Hence, Figure 5 is the finalized graph depicting the contemporaneous relationship among the twelve prices and rates. Gulf price (GF) and barge rates (BR) are the information initiators, while the other corn prices are information receivers.

Figure 4. Directed Acyclic Graph on Innovations from Corn Prices and Freight Rates with a One-Lag ECM (See Table 1 for definition of variables)

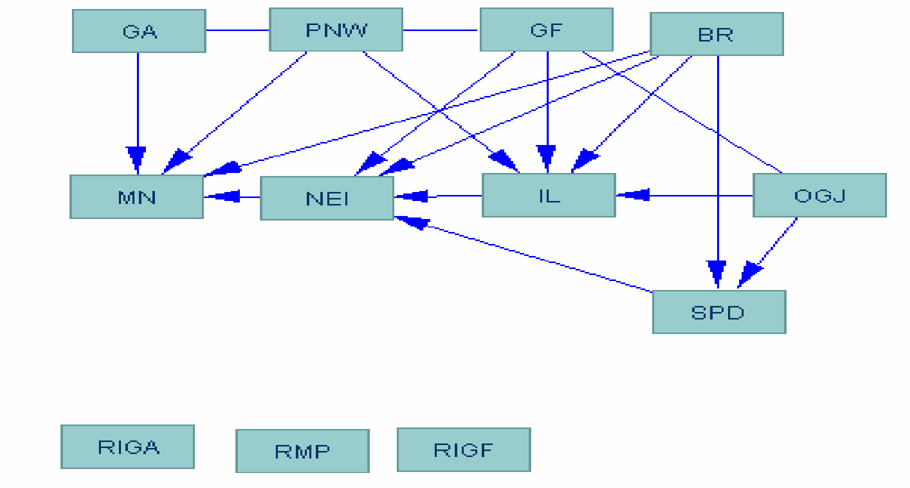
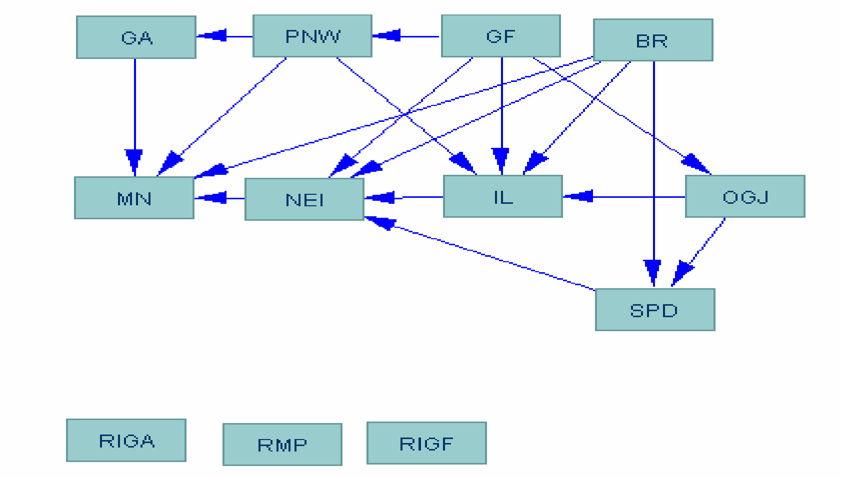


Figure 5. Finalized Directed Acyclic Graph on Innovations from Corn Prices and Freight Rates with a One-Lag ECM (See Table 1 for definition of variables)



Based on the estimated results of one-lag ECM model together with the causal relationship in Figure 5, a summary of the dynamic influence of transport rates on corn prices over time is presented in Table 7, as it gives the percentage of the forecast error uncertainty accounted for by earlier innovations (new information from each market) in each of the six corn prices. These numbers partition the uncertainty in each class at horizons of zero, one and twelve months ahead. For example, for the export corn price at PNW (PNW) ports, the uncertainty associated with current price is explained by current shocks in its own price [30.11%] and current shocks in Mississippi Gulf corn price (GF) [69.89%]. If we move ahead one period (one month), the uncertainty in PNW price is still primarily influenced by the GF price [63.35%] and own price [25.46%]. The influence of transport costs gradually emerge at one month with 0.29 percent of variation in the PNW corn price attributable to barge rates, 6.41 percent due to rail rates (0.90% + 5.18% + 0.40%), and 1.38 percent a result of ocean rate variability (0.97% + 0.41%). At the longer horizon of one year, about 57.6 percent of the uncertainty in PNW price is attributed to all freight rates, with barge, rail and ocean rates accounting for 12.15 percent, 15.36 percent (3.82% + 11.39% + 0.15%), and 30.12 percent (29.47% + 0.65%), respectively. Ocean rates linking the Gulf and Japan (OGJ) have the most significant impact on corn price variability. Similar findings can be observed for other corn prices (GF, MN, NEI, IL, and GA). In general, shocks in barge rates (BR) explain about 10-13 percent of the variation in corn prices. Rail rates linking Minnesota to PNW ports (RMP) are the most influential rail rates, explaining 11-13 percent of the variation in corn prices. Shocks in the three evaluated rail rates explain 15-21 percent of corn price variation in the long-run. Shocks in the two evaluated ocean shipping rates (OGJ and SPD) are responsible for17-30 percent of the variation of corn prices and, accordingly have the greatest influence of any mode on corn price.

The six analyzed transportation rates explain approximate 42-64 percent of the variation in corn prices, with most of the variation attributed to the ocean shipping rates linking the Gulf and Japan (OGJ), rail rates linking Minnesota and PNW ports (RMP), and barge rates on the Upper Mississippi and Illinois Rivers (BR). It is important to understand and interpret the percentage correctly. The estimated percentage is the percent of the variation in the *forecast error*, not the corn price. Clearly shocks in ocean rates that link the Gulf to Japan, rail rates linking Minnesota and PNW, and barge rates on the River influence the variability in corn prices. Previous studies have shown that hedging of ocean freight rates reduces the price uncertainty of grain, and have observed that the volatility of barge rates contribute to uncertainty in grain prices (Haigh and Holt (2000); Haigh and Bryant(2001)). Results obtained in this study correspond to the earlier findings.

CONCLUDING REMARKS

Studies evaluating the relationship between grain prices and transportation rates are often conducted in a static perspective. On the other hand, most studies associated with market integration employ time-series methodology; however, they usually ignore the transportation rates or alternative transportation modes linking these markets. The objective of this study is to better understand the impact of transportation rates on grain prices in export and domestic markets over time. The grain evaluated in this study is corn due to its strong transportation demand. This study examines two dominant grain export ports (the Mississippi Gulf and PNW), three primary grain production and consumption markets in the north-central U.S., and Georgia which represents southeast U.S. corn demand. Also, included in the analyses are barge rates linking the north central U.S. to the Gulf, ocean shipping rates linking the two major U.S. port areas to Asia, and rail rates linking the Midwest to Georgia, the Gulf and PNW. There are a total of twelve monthly series extending from 1990-2002.

Employing time-series methods and directed acyclic graphs analysis, the study has evaluated the dynamic influences of transportation rates on grain prices. Twelve evaluated series were found to be linked in eleven long-run cointegration relationships. A test of exclusion indicated the twelve prices and rates are in the same cointegration space while the test of weak exogeneity suggested only ocean rates linking the Gulf to Japan do not respond to perturbations in the long-run.

The ECM analysis shows that shocks in transportation rates (barge, rail, and ocean) explain a considerable proportion of the variation in corn prices in the long run [42-64%]. Shocks in ocean rates and barge rates impact corn prices in contemporaneous time. The volatile ocean freight rates are the most important source contributing to the variation in grain prices in the long run; while shocks in barge rates likely explain less than 15 percent of the variation in corn prices. The analyzed rail rates do not immediately influence corn prices, however; in the long run up to 13 percent of the variation in corn prices are a result of shocks in rail rates that link the Midwest and the PNW port area. The high proportion of variation in corn prices explained by variation in transportation rates suggests the importance of transportation rates in corn price determination.

Table 7. Forecast Error Decomposition on Selected Corn Prices and Freight Rates

Horizon	PNW	GF	MN	NEI	IL	GA	BR	RIGF	RMP	RIGA	OGJ	SPD
(PNW)												
0	30.11	69.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	25.46	63.35	0.06	0.66	0.35	1.97	0.29	0.90	5.18	0.40	0.97	0.41
12	11.54	27.45	1.84	0.33	0.44	0.96	12.15	3.82	11.39	0.15	29.47	0.65
(GF)												
0	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	7.02	87.75	0.02	0.02	0.03	0.19	0.32	0.71	3.15	0.68	0.09	0.01
12	6.13	35.39	1.75	0.21	0.37	0.46	12.83	3.55	11.49	0.23	27.22	0.38
(MN)												
0	4.56	74.46	4.54	3.56	1.92	0.25	9.72	0.00	0.00	0.00	0.92	0.07
1	9.46	72.68	2.74	2.09	1.07	0.25	7.13	0.63	3.11	0.27	0.51	0.05
12	8.57	39.82	2.26	1.08	0.63	0.70	10.27	3.70	13.24	0.13	19.06	0.54
(NEI)												
0	0.88	77.94	0.00	6.75	3.65	0.00	8.92	0.00	0.00	0.00	1.75	0.13
1	3.66	77.12	0.06	3.86	2.16	0.18	7.76	0.61	3.02	0.52	0.99	0.07
12	6.77	41.60	1.23	1.70	1.02	0.37	10.44	3.37	12.84	0.25	19.92	0.51
(IL)												
0	2.34	80.99	0.00	0.00	9.76	0.00	5.20	0.00	0.00	0.00	1.71	0.00
1	9.76	76.30	0.00	0.05	5.06	0.15	3.14	1.43	2.83	0.39	0.87	0.02
12	8.14	36.18	1.48	0.20	1.91	0.80	10.96	4.38	13.22	0.15	22.13	0.45
(GA)												
0	13.24	30.72	0.00	0.00	0.00	56.05	0.00	0.00	0.00	0.00	0.00	0.00
1	10.73	38.66	0.00	0.12	0.10	40.82	0.01	5.59	3.43	0.46	0.08	0.00
12	7.42	26.22	0.17	0.17	0.26	14.65	11.16	7.33	13.43	0.18	17.52	0.06

REFERENCES

Babcock, M.W. and W. German. "Forecast of Water Carrier Demand to 1985." *Proceedings of the Transportation Research Forum* 24, (1983):249-257.

Bernanke, B.S. "Alternative Explanations of the Money-income Correlation." *Carnegie-Rochester Conference Series on Public Policy* 25, (1986):49-100.

Bessler, D.A. and S. Lee. "Money and Prices: U.S. Data 1869-1914 (A study with directed graphs)." *Empirical Economics* 27, (2002):427-46.

Bessler, D. A. and J. Yang. "The Structure of Interdependence of International Stock Markets." *Journal of International Money and Finance* 22(2003):261-87.

Chickering, D.M. "Optimal Structure Identification with Greedy Search" *Journal of Machine Learning Research* 3, (2002):507-554.

Dickey, D.A. and W.A. Fuller. "The Likelihood Ratio Statistics for Autoregressive Time Series with A Unit Root." *Journal of the American Statistical Association* 74, (1981):427-31.

Doan, T. *RATS: User's Manual 4.0*. Estima, Evanston, IL, 1992.

Fellin, L. and S. Fuller. "Effect of Proposed Waterway User Tax on U.S. Grain Flow Patterns and Producers." *Journal of the Transportation Research Forum* 36, (1997):11-25.

Fuller, S., L. Makus and M. Taylor. "Effect of Railroad Deregulation on Export Grain Rates." *Northcentral Journal of Agricultural Economics* 5, (1983):149-63.

Goodwin, B.K, and T.C. Schroeder. "Price Dynamics in International Wheat Markets" *Canadia Journal of Agricultural Economics* 39, (1991):237-254.

Haigh, M.S. and D.A. Bessler. "Causality and Price Discovery: An Application of Directed Acyclic Graphs." *Journal of Business* 77, (2004):1099-1121.

Haigh, M.S. and H.L. Bryant. "The Effect of Barge and Ocean Freight Price Volatility in International Grain Markets" *Agricultural Economics* 25, (2001):41-59

Haigh, M.S. and M.T. Holt. "Hedging Multiple Price Uncertainty in International Grain Trade." *American Journal of Agricultural Economics* 82, (2000):881-896.

Hannan, G. and B. Quinn. "The Determination of the Order of an Autoregression." *Journal of the Royal Statistical Society* Series B, (1970):190-95

Hansen, H. and K. Juselius. *CATS in RATS: Cointegration Analysis of Time Series*, Estima: Evanston, 1995.

Hauser, R.J., J. Beaulieu, and C.P. Baumel. "Impacts of Inland Waterway User Fees on Grain Transportation and Implied Barge Rate Elasticities." *The Logistics and Transportation Review* 21, (1985):37-47.

Hoover, K.D. "Automatic Inference of the Contemporaneous Causal Order of A System of Equations." *Econometric Theory*, 21, (2005):69-77.

Johansen, S. "Statistical Analysis of Cointegration Vectors." *Journal of Economic Dynamics and Control* 12, (1988):231-54.

Johansen, S. "Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models." *Econometrica* 59, (1991):1551-80.

Johansen, S. "Determination of Cointegration Rank in the Presence of A Linear Trend." *Oxford Bulletin of Economics and Statistics* 54, (1992):383-397.

Johansen, S. "Identifying Restrictions of Linear Equations With Applications to Simultaneous Equations and Cointegration." *Journal of Econometrics* 69, (1995):111-132.

Johansen, S. and K. Juselius. "Maximum Likelihood Estimation and Inference on Cointegration-with Application to the Demand for Money.: *Oxford Bulletin of Economics and Statistics* 52, (1990):169-210.

Johansen, S. and K. Juselius. "Identification of the Long-run and the Short-run Structure: An Application to the ISLM Model." *Journal of Econometrics* 63, (1994):7-36.

Lutkepohl, H. and H. Reimers. "Impulse Response Analysis of Cointegrated Systems." *Journal of Economic Dynamics and Control* 16(1992):53-78.

McKenzie, A.M. "The Effects of Barge Shocks on Soybean Basis Levels in Arkansas: A Study of Market Integration." *Agribusiness* 21, (2005):37-52.

Pearl, J. "Propagation and Structuring in Belief Networks." *Artificial Intelligence* 29, (1986):241-88.

Pearl, J. "Causal Inference from Indirect Experiments." *Artificial Intelligence in Medicine* 7, (1995):561-82.

Pearl, J. *Causality*, Cambridge: Cambridge University Press, 2000.

Phillips, P.C.B. and P. Perron. "Testing for A Unit Root in Time Series Regression," *Biometrika*, 75, (1988):335–346.

Schwarz, G. "Estimating the Dimension of a Model." *Annals of Statistics* 6(1978):34-58.

Sims, C. "Macroeconomics and Reality." *Econometrica* 48, (1980):1-48.

Spirtes, P., C. Glymour and R. Scheines. *Causation, Prediction, and Search*. 2nd ed. New York, NY. MIT Press. 2000.

Swanson, N.R. and C.W.J. Granger. "Impulse Response Functions Based on A Causal Approach to Residual Orthogonalization in Vector Autoregressions." *Journal of the American Statistical Association* 92, (1997):357-67.

U.S. Department of Agriculture, Agricultural Marketing Service. *Grain Transportation Report.* Various issues at 2005. Available at http://www.ams.usda.gov/tmdtsb/grain/

U.S. Department of Agriculture, National Agricultural Statistics Service. *Statistical Highlights of U.S. Agriculture, 2004/2005.* U.S. Department of Agriculture, Statistical Bulletin 1003, April 2005.

Wang, Z. and D.A. Bessler. "A Monte Carlo Study on the Selection of Cointegrating Rank Using Information Criteria," *Econometric Theory* 21, (2005):593-620.