Analysis of Dynamic Interrelationships between Transportation Rates and Grain Prices

Tun-Hsiang (Edward) Yu
Department of Agricultural Economics
Texas A&M University
College Station, TX 77843-2124
Tel: (979) 845-6791
Fax: (979) 845-6378
E-mail: t-yu@tamu.edu

David A. Bessler
Department of Agricultural Economics
Texas A&M University
College Station, TX 77843-2124
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 77843-2124
Tel: (979) 845-1941
Fax: (979) 845-6378
E-mail: sfuller@tamu.edu

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Denver, Colorado, August 1-4, 2004

Analysis of Dynamic Interrelationships between Transportation Rates and Grain Prices

Abstract

Transportation rates are vital componenets in the structure of U.S. grain exports. In this paper we study the dynamic properties of corn and soybean prices, and barge, rail and ocean shipping rates using time series analysis on monthly 1992-2001 data. Using Error Correction Model and Directed Acyclic Graphs, we capture the interconnectivity between the transportation rates and grain prices at selected domestic and export markets. We find Illinois processor prices are important sources of price discovery for both corn and soybeans. Further, barge rates explain about 2-4% of the variation in grain prices while rail rates explain about 10-12% of the variation in corn and soybean prices.

Analysis of Dynamic Interrelationships between Transportation Rates and Grain Prices

Introduction

The United States is the world's primary producer of grain. In addition to fulfilling its own demand, the U.S. also supplies a large amount of grain to other countries, especially in Mexico and Asia. Most export-bound grain movements are carried by maritime transportation from ports located in the lower Mississippi River (Gulf) and the Pacific Northwest (PNW). The former dominates export volume handling about 70 percent of U.S. annual corn and soybean outflow. The importance of the lower Mississippi River port area largely results from an efficient barge transportation system that links the north central United States, an intense grain production region, to the Gulf. This low-cost barge transportation on the upper Mississippi and Illinois Rivers has enabled the north central U.S. to efficiently compete in international grain markets.

There are several alternatives to the Gulf export market and barge transportation for north central U.S. grain production. For instance, grain companies in Iowa or Minnesota may ship grain to Asia via rail to the PNW ports where it is transferred to ocean vessels instead of by Mississippi River barges to the Gulf if barge rates increase considerably. Similarly, grain traders in Illinois may select rail service rather than barge transportation on the Illinois River to deliver their grain to the Gulf. In addition to exports, grain companies in the north central U.S. can send grain to domestic markets via rail or truck since the domestic demand accounts for about 80 percent and two-thirds of total U.S. corn and soybean disappearance, respectively (USDA/ERS). Theoretically, the decision of selecting which market and associated shipping route primarily depends on the grain prices at destination markets and the rates of involved transportation services, such as barge, rail and maritime. As a result, the grain prices and rates of those transportation modes may interact closely.

Previous studies generally support the effect of barge or rail rates/fees on grain prices and flow (Babcock and German; Fellin and Fuller; Hauser, Beaulieu, and Baumel; Miljkovic et al.). The interrelationship between grain transportation modes (barge and rail) has also been evaluated and observed by several of studies (Johnson; Shelton 1912c, 1914; Kelso; McCarney; Sorenson; Fedeler and Heady; Fuller, Makus, and Taylor; McDonald). These studies provided considerable information and knowledge of rail and barge transportation and agricultural markets; however, none of these studies examined the interaction of grain prices and transportation rates in a dynamic framework. Also, most studies failed to consider alternative markets and transportation. The objective of this paper is to explore the dynamic relationships among north central U.S. and export grain prices and barge rates on the upper Mississippi and Illinois Waterways, rail rates linking the Midwest to export port areas, and ocean rates that link the lower Mississippi ports and the PNW to Asia. Using Error Correction Model (ECM) and Directed Acyclic Graphs (DAG), we attempt to capture the interconnectivity between grain prices and freight transportation markets.

Method of Analysis

To accomplish study objectives the methods of dynamic econometrics are applied to aggregate time series data on seven grain prices, including corn and soybeans prices at inland locations in both Illinois, Iowa, and Memphis, and export grain prices at the Gulf and PNW; also six transportation rates: barge rates linking the upper Mississippi/Illinois rivers to lower Mississippi river ports, rail rates linking Illinois to the Gulf and Memphis, rail rates linking Minnesota and Iowa to PNW, and ocean freight rates linking the Gulf and Japan also the PNW and Japan. In addition, directed graphs are used to identify contemporaneous causality among these variables.

Error Correction Model (ECM)

In this study, the engine of analysis is the error correction model (ECM). Since we are studying grain prices from selected domestic and export markets and the rates of transportation services linking the north central U.S. to those destinations, we presumably expect those prices to be non-stationary and cointegrated. Let P_t denote a vector that includes m nonstationary prices (m=13 in this study). Assuming existence of cointegration, the data generating process of P_t can be appropriately modeled in an error correction model (ECM) with k-1 lags (which is derived from a levels vector autoregression (VAR) with k lags):

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

$$e_t \sim Niid(0, \Sigma) \qquad (2)$$

where Δ is the difference operator ($\Delta P_t = P_t - P_{t-1}$), P is a (13x1) vector of prices measured at time t, $\Pi = \alpha\beta'$, Γ_i a (13x13) matrix of coefficients relating price changes lagged *i* period to current changes in prices, Π is a (13x13) matrix of coefficients relating lagged levels of prices (not changes) to current changes in returns and ε_t is a (13x1) vector of innovations. (Actually Π may be of order 13x14 if we have a constant (to be tested for below) in the cointegration space.)

The parameters on the above ECM can be partitioned to provide information on the long-run, short-run and contemporary structure. The long-run structure can be understood through testing hypotheses on the β; the short-run structure can be studied through testing hypotheses on α and Γ_i (Johansen and Juselius, 1994; Juselius; Johansen, 1995). Finally, the contemporaneous structure can be summarized through structural analysis of e_t or more conveniently though the directed graph analysis of Σ, as described recently in Bessler and Lee and Bessler and Yang.

The number of cointegration relations, *r*, can provide preliminary information on the long-run structure of market interdependence. The rank of Π (i.e., row rank of β) determines the number of cointegrating vectors. Trace tests on the eigenvalues of Π are used to determine *r* in our thirteen grain prices and transportation rates (Johansen, 1991; Johansen and Juselius, 1990).

It is well recognized that, like standard VAR models, individual coefficients of the ECM are hard to interpret. Under such cases, innovation accounting may be the best description of the dynamic structure (Sims; Lutkepohl and Reimers; Swanson and

Granger). We estimate the parameters of equation (1) using the maximum likelihood procedure of Johansen (1992). We re-express the error correction model as a levels VAR by algebraic manipulation of the estimated coefficients. We then conducted innovation accounting based on the equivalent levels VAR to summarize the dynamic interactions among the grain prices and transportation rates.

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, Scheines). We investigate the use of directed graphs in providing help in providing 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 structure found with the directed graphs on contemporaneous structure (see Bernanke or Doan).

Directed Acyclic Graphs (DAG)

The directed acyclic graphs (DAGs) have been the center of recent research efforts in the computer science and philosophy. Here we offer a very short summary of the ideas and description of useful algorithms for applications with observational (non-experimental) data.

Directed graphs emanate from the field of mathematics and computer science, and have been studied for decades. The recent development on their use in discovery algorithms is due work of Spirtes, Glymour, Scheines; Pearl (2000), and their co-authors. The relevance of this work to economic scientists is that it facilitates the inference of causal relations from observational data (Swanson, 2002; Lauritzen and Richardson, 2002).

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:

$$pr(v_1, v_2, \cdots, v_n) = \prod_{i=1}^{n} pr(v_i \mid \pi_i), \qquad (3)$$

where *pr* is the probability of variables v_1 , v_2 , …, v_n. The symbol, π_i, refers to the realization of a subset of variables that precede (come before in a causal sense) v_i in order (i = 1, 2, …, n). The symbol, Π, refers to the multiplication operator. Pearl (1986, 1995) proposed d-separation as a graphical characterization of the independence relations given by equation (3). Two vertices (for example, variables X and Y) are d-separated if the information flow between them is blocked. This occurs when: a) one variable is a common cause, say W in the graph $X \leftarrow W \rightarrow Y$ or a mediator in a causal chain, say U in the graph $X \rightarrow U \rightarrow Y$, and we condition on W or U; or b) if a variable Z is the middle variable in an inverted fork ($X \rightarrow Z \leftarrow Y$) and we do not condition on Z or any of its descendents (descendents are not shown here).

If we formulate a directed graph in which the variables corresponding to π_i are represented as the parents (direct causes) of v_i, then the independencies implied by equation (1) can be read off the graph using the criterion of d-separation. Geiger *et al.* (1990) showed that there is a one-to-one correspondence between the set of conditional independencies, $X \perp Y \mid Z$, implied by equation (1) and the set of triples (X, Y, Z) that satisfy the d-separation criterion in a graph G. Specifically, if G is a directed acyclic graph with variable set V, and if X and Y are in V, and Z is also in V, then the implied linear correlation between X and Y in G, conditional on Z is zero if and only if X and Y are d-separated given Z. Here, “acyclic” means that one cannot return to any starting variable by following arrows that lead away from the starting variable. Thus, the chain relationship $X \rightarrow Y \rightarrow X$ is not allowed in a final directed graph.

Spirtes, Glymour, Scheines; and Pearl (2000) present algorithms with similar structures and outputs for inference on directed acyclic graphs from observational data. The former is labeled PC algorithm, embedded in the software TETRAD II and III (see the offering at http://www.phil.cmu.edu/projects/tetrad/ and Scheines et al., 1994) and described in Spirtes et al. (2000); the latter is IC algorithm presented in Pearl (2000, pp.50-51). We do not give a description of PC algorithm here but refer the readers to Bessler and Akleman or the TETRAD site given above.

Variables and Data

This section offers a brief discussion of selected variables used to measure the dynamic interaction among grain prices and transportation rates in this study. These prices are aggregated monthly averages that extend from 1992 through 2001. All grain prices and transportation rates were obtained from the U.S. Department of Agriculture, Agricultural Marketing Service. The descriptive statistics for these variables are presented in Table 1.

Spot export corn prices at PNW (CPPNW) and the Mississippi Gulf (CPGF) were collected as were three interior corn bid prices in southeast Iowa (CPSEI), south central

Illinois (CPILP) and Memphis (CPMEM) (Table 1). These three interior prices were selected since there is considerable number of grain processors located in these regions. The Illinois Department of Agriculture collects an explicit corn processor price; unfortunately, the corn processor prices were not available until October 1992. Therefore, the south central Illinois corn price is used as a proxy of the processor price since these two prices exhibit very high correlations (0.9993). The highest mean of the five corn prices is in the PNW port area and the lowest is found in southeast Iowa. The export corn prices and Memphis corn prices have smaller coefficient of variations (C.V.) as compared to the Iowa and Illinois prices. Soybean prices at the Mississippi Gulf ports (SPGF) and central Illinois processors (SPILP) are used in this study (Table 1). Central Illinois soybean processors are located in a central Illinois region that extends from the Mississippi river to the Indiana border.

Barge rates (BR) used in this study is a weighted average rate generated from the barge rates of north Iowa (McGregor to Clinton, IA) and south Peoria (Peoria to Beardstown, IL). Those two spot grain barge rates reflect the current rate as a percent of the historic benchmark tariff rate (Southbound Barge Freight Call Session Basis Trading Benchmark, July, 1979): the current \$/ton rates (short ton) were calculated by multiplying the quoted weekly rate (% of benchmark rate) by the historic benchmark rate. Since the upper Mississippi River is generally closed in winter, the rates are not available in the frozen period. Illinois River is navigable year round; however, the volume of grain moved on the Illinois River is significantly less than that on the upper Mississippi River while the latter is open. Thus, we construct an average rate weighted by the respective volume of grain moved by barge on the upper Mississippi River and Illinois River to represent grain barge rate in this study.

Monthly average rail rates linking Illinois to the Mississippi Gulf (RILGF), Minnesota and Iowa to PNW ports (RMNPNW), and Illinois to Memphis (RILMEM) are generated from the annual Carload Waybill Sample data. Clearly, the rail rates are higher at increased distance. The RMNPNW is more than double the RILGF and four times greater than RILMEM. In addition, the RILGF is usually considered as a competitive rate to the barge rates linking north central U.S. to the Gulf (BR). Here, the average monthly BR is slightly lower than RILGF (Table 1).

Two ocean shipping rates, Gulf to Japan (OGFJP) and PNW to Japan (OPNWJP), are also included in this study. Since Asia is the primary importer of U.S. grain while Japan is the leading importer among Asian countries, the ocean shipping rates linking the U.S. ports to Japan is important to the export price. The OGFJP is about $10/ton higher than OPNWJP on average.

Results

We used Schwarz Loss and Hannan and Quinn Φ measures (not reported here to save space) to determine lag lengths from unrestricted vector autoregressions (VAR) fit to these thirteen series (in levels). The measures are fit with eleven monthly indicator variables in each VAR equation to account for deterministic seasonality. Our search is over lags of zero through six periods. Both measures suggest a VAR of one lag. We follow Hansen and Juselius and fit an error correction model with one lag of first differences and one lag of levels.

Table 2 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 2 by the "#" sign at six cointegrating vectors with the constant inside the cointegrating space.

Table 3 gives a test of stationarity on the null hypothesis that the seven grain prices and six transportation rates is stationary. The likelihood ratio test shows all prices and rates are non-stationary since the calculated χ^2 statistic is greater than the 5% critical value (12.59) in all cases.

It is possible that, while six long-run stationary relations are present in our thirteen grain prices and transportation rates, one or more of the markets will not be a part of any of these six vectors. Table 4 presents tests in which each market is excluded from the cointegration space. The null hypothesis for each row of the table is that the market listed in the far left-hand column is not in the cointegration space. The test is distributed chi-squared with six degrees of freedom (as we are placing a zero associated with market i in each of the six vectors). We reject the null for all prices but the rail rates associated with Illinois to Memphis (RILMEM), suggesting that each price except RILMEM is part of at least one cointegrating vector. Notice, however, that the chi-squared statistic of RILMEM (12.12) is very close the 5% critical value (12.59), suggesting this rail rates may still be considered in the cointegration space.

Table 5 gives test of weak exogeneity on each price. Here we are asking the question of whether each grain or transportation market responds to perturbations in the cointegrating space. So, if our price data in period t is such that we are out of long-run equilibrium, as represented by any one of the six cointegrating vectors, does market i respond to that disequilibria? Our null hypotheses tested for each row is that market i does not respond to perturbations in any of the long run equilibrium (cointegrating vectors). Using a 5% significance level, we see that most prices, except one grain price (CPPNW) and one transportation rates (OGFJP), appear change to restore the long-run equilibriums when new information upsets them.

Figure 1 gives the directed acyclic graph derived from the contemporaneous correlation between innovations in each of the thirteen prices. Using PC algorithm, causality flows in contemporaneous time are identified among evaluated grain prices and transportation rates. Results are offered at both the 15% and 20% significance level. Results at the two significance levels are similar. Notice there are five bi-directed edges in the 20% significance level graph (CPSEI↔CPGF; CPPNW↔CPGF; CPMEM↔CPSEI; CPMEM↔CPPNW; CPSEI↔BR), which indicates the possibilities of omitted variables in this DAG analysis. Since we lack of additional variables and observations, we employ other studies' findings and different significance level to determine the direction. Using 12% significance level, we found CPSEI→CPGF. At

15% significance level, the causal relationship of CPPNW→CPGF and CPSEI→CPMEM is observed. The causality of BR→CPSEI is suggested by Haigh and Bessler's study on the relationship between daily barge rates and corn prices at hinterland and the Gulf ports. Last, the direction of causality between CPMEM and CPPNW is arbitrarily determined, the results are, however, robust when the reserve relationship is imposed. In addition to those bi-directed edges, the un-directed edge is also observed between RILGF and OPNWJP as well as GPILP and CPGF at both 15% and 20% significance level. Following the procedures proposed by Haigh and Bessler, we studied all possible acyclic graphs from the pattern generated by PC algorithm. We use seemingly unrelated regression to fist a structural equation model on the innovations for each of these alternatives. Each alternative is scored with the modified Schwarz-loss metric and the model with the minimize Schwarz loss is selected. From the Schwarz loss statistic, we determine the relationship of those two un-directed edges is: RILGF→PNWJPN and CPILP→CPGF.

Figure 2 is the graph depicting the contemporaneous relationship among the thirteen prices. Corn price at the south central Illinois (CPILP) and Memphis (CPMEM) are exogenous in contemporaneous time, so is the rail rates linking Illinois to the Gulf ports (RILGF). Export corn and soybean prices at the Gulf (CPGF, SPGF) and the ocean freight rates linking the Gulf to Japan (OGFJP) are information "sinks." As arrows are directed into these markets (their representations) and no arrows are directed out. We interpret this result as indicating that these two export prices and associated ship rates are receivers of information in contemporaneous time. The remaining prices, except for the rail rates of Illinois to Memphis (RILMEM), both receive information (have at least one arrow into their graphical representation) and send information (have at least one arrow emanating from their graphical representation).

Table 6 offers an overall summary of the relationship between each price, as it gives the percentage of the forecast error uncertainty accounted for by earlier innovations (new information from each market) in each of the thirteen grain prices and transportation rates. These numbers partition the uncertainty in each class at horizons of zero, one and twelve months ahead. For example, for export corn price at PNW (CPPNW), the uncertainty associated with current prices is explained by current period shocks in its own price [19.48%], shocks in current period south central Illinois corn price (CPILP) [76.47%], and Memphis corn price (CPMEM) [4.04%]. If we move ahead to one period (one month) ahead, the uncertainty in CPPNW is still primarily influenced by the CPILP [73.68%] and itself [16.37%]. At the long horizon of one year ahead the uncertainty in CPPNW is still affected by CPILP considerably [56.68%]. Similar partitions can be found for all other corn prices (CPGF, CPSEI, CPILP, and CPMEM). For soybean markets, Illinois soybean processor price (SPILP) is the principal resource to explain the uncertainty of itself and the export price at Gulf (SPGF). The evidence presented in Table 6 indicates clearly that price uncertainty in corn and soybeans markets is explained primarily by uncertainty in the Illinois grain price.

Barge rates (BR) explain about 2-4% of the variation in all corn prices; but less than 1% of the variation in soybean prices. Rail rates of Minnesota and Iowa to PNW (RMNPNW), the most influential rail rates, explain 6-11% of the variation in grain prices. The three evaluated rail rates explain together 10-12% of grain prices variation in the long-run. Two evaluated ocean shipping rates present very modest explanation power (<1%) in the variation of grain prices.

In view of the interdependence among transportation modes, variation in BR is explained by three rail rates together about 16%, while the RILGF is the primary influential source [12.31%]. Reciprocally, variation in RILGF is explained by BR about 14.21% in the long-run. This finding supports the competition relationship between barge transportation on the Illinois River and railroad linking Illinois to Gulf. In addition, barge rates and two evaluated ocean shipping rates do not present strong interrelationship in Table 6. As expected, the two ocean shipping rates (OGFJP, OPNWJP) are basically reacting to each other. Interestingly, the interdependence between some rail rates and ocean shipping rates is found. Variation in RILGF is explained by ocean shipping rates linking the Gulf and Japan (OGFJP) about 10% in the long-run. In contrast, RILGF is able to explain about 7% of the variation in OGFJP. Surprisingly, the ocean rates of PNW to Japan (OPNWJP) is explained by RILGF about 17.24% in the long-run, which deserves additional research.

Figure 3 gives the dynamic response of each series to a one-time-only shock in each series. The responses are normalized by dividing each response by the historical standard deviation of the innovation in each series. This allows us to compare responses across prices. We present all responses on one graph because we are not to convey explicit numerical responses but to give the reader a sense or feel for the responses from viewing the overall pattern in one graph. The pattern that jumps out of Figure 8 is the strong influence of the Illinois corn price (CPILP) on every other corn prices. The responses give us information that coheres well with that discussed above from Table 6. Illinois grain processor prices dominate in the long-run.

Conclusions

Studies evaluating the relationships between grain prices and transportation rates are primarily conducted in a static perspective. The objective of this study is to better understand the dynamic relationships between grain prices at export and domestic markets and the rates of related transportation modes. We have studied monthly corn and soybean prices in the north central U.S. and Memphis, export prices at the Gulf and PNW, barge rates linking the north central U.S. to the Gulf, rail rates linking the Midwest to Memphis, the Gulf and PNW, and ocean shipping rates linking the two ports to Asia over the years 1992-2001. Results suggest that the thirteen evaluated grain prices and transportation rates are tied together in six long-run cointegration relationships. Test of exclusion indicates all of those thirteen prices/rates are in this cointegration space while the test of weak exogeneity suggests only two prices/rates (CPPNW and OGFJP) did not respond to shocks (perturbations) in the long-run (cointegrating space).

Time series analysis and Directed Acyclic Graphs suggest Illinois processor prices are important sources of price discovery for both corn and soybeans: south central Illinois corn price (a proxy of Illinois corn processor price) explains at least 50% of the variation in other corn prices in the long-run while Illinois soybean processor price explains about 55% of the Gulf export soybean price variation. In addition, findings indicate that changes in barge rates account for about 2% to 4% of the variation in corn prices and less than 1% of the variation in soybean prices. The relative importance of barge rates on prices on corn and soybeans is not identical. The possible explanation is that barge rates are the same for both commodities but the soybean prices are about 2 times higher than corn prices, hence the proportion of the variation in corn prices greater than soybean prices. The three evaluated rail rates explain together about 10-12% of grain price variation while the two selected ocean shipping rates exhibit very modest (<1%) influence on the variation in grain prices contemporaneously or one year ahead.

The dynamic interrelationships between the six evaluated transportation rates also present some interesting findings. Variation in barge rates is explained by three rail rates together about 16%. The rail rates linking Illinois to Gulf and barge rates explain similar percentage of the variation in each other, indicating the close relationship between barge transportation on the Illinois River and railroad linking Illinois to Gulf. In addition, barge rates explain about 0-3% variation in two evaluated ocean shipping rates. Interestingly, about 10% of the variation in rail rates linking Illinois to the Gulf is explained by ocean shipping rates linking the Gulf to Japan in the long-run. In contrast, this rail rates explain about 7% of the variation in the shipping rates linking the Gulf to Japan. Surprisingly, the ocean rates linking PNW to Japan is explained by the same rail rates about 17.24% in the long-run, which deserves additional research.

In summary there are considerable interrelationships among the actors in the U.S. grain export market. Both corn and soybeans prices are influenced by transportation rates with feedback.

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):49-99.

Bessler, D.A. and Akleman, D.G. "A Farm Prices, Retail Prices, and Directed Graphs: Results for Pork and Beef." *American Journal of Agricultural Economics* 80(1998):1145-1150.

Bessler, D.A. and S. Lee. "Money and Prices: U.S. Data 1869-1914 (A study with directed graphs)." *Empirical Economics* 27(2002):427-446.

Bessler, D. A. and J. Yang. "The Structure of Interdependence of International Stock Markets." *Journal of International Money and Finance* 22(2003):261-287.

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

Fedeler J.A. and E.O. Heady. "Grain Marketing and Transportation Interdependencies: A National Model." *American Journal of Agricultural Economics* 58(1976):224-235.

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):149-163.

Geiger, D., T. Verma and J. Pearl. "Identifying Independence in Bayesian Networks." *Networks* 20(1990):507-534.

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.

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.

Johnson, E.R. "Factors Affecting the Future of Water Transportation in the United States." *American Economic Association Quarterly,* 10(1909):277-283.

Juselius, K. "Do Purchasing Power Parity and Uncovered Interest Rate Parity Hold in the Long Run? An Example of Likelihood Inference in a Multivariate Time-series Model." *Journal of Econometrics* 69(1995):211-240.

Kelso, H. "Waterways Versus Railways." *The American Economic Review* 31(1941):537-544.

Lauritzen, S.L. and T.S. Richardson. "Chain Graph Models and Their Causal Interpretation(with discussion)." *Journal of the Royal Statistical Society*, Series B, 64(2002)321-361.

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

McCarney, B.J. "Oligopoly Theory and Intermodal Transport Price Competition: Some Empirical Findings." *Journal of Land Economics* 46(1970):474-478.

McDonald, J.M. "Competition and Rail Rates for the Shipment of Corn, Soybeans and Wheat." *Rand Journal of Economics* 18(1987):151-163.

Miljkovic, D., G.K. Price, R.J. Hauser, and K.A. Algozin. "The Barge and Rail Freight Market for Export-Bound Grain Movement from Midwest to Mexican Gulf: An Econometric Analysis." *Transportation Research Part E* 36(2000):127-137.

Pearl, J. "Propagation and Structuring in Belief Networks." *Artificial Intelligence* 29(1986):241-288.

Pearl, J. "Causal Inference from Indirect Experiments." *Artificial Intelligence in Medicine* 7(1995):561-582.

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

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

Scheines, R., P. Spirtes, C. Glymour and C. Meek. 1994. *TETRAD II: User's manual and software*. Lawrence Erlbaum Associates, Inc., New Jersey, 1994.

Sorenson, L.O. "Rail-Barge Competition in Transporting Winter Wheat." *American Journal of Agricultural Economics* 55(1973):814-819.

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

Swanson, N.R. "Causality: Models, Reasoning, and Inference." *Journal of Economic Literature* 40(2002):925-926.

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):357-367.

U.S. Department of Agriculture-Economic Research Service. *Outlook Reports* (Feed Yearbook; Oil Crops Yearbook). Available at http://www.ers.usda.gov/publications/outlook/ (Accessed May 1, 2004).

Table 1. Descriptive Statistics Selected Monthly Corn/Soybean Prices, Barge, Rail and Ocean Shipping Rates, 1992 – 2001.

Prices/Rates	Mean	S.D.	Min.	Max.	C.V.
Corn Prices					
Pacific Northwest (CPPNW)	108.05	23.50	75.18	199.70	0.22
Mississippi Gulf (CPGF)	98.65	22.75	67.34	184.64	0.23
Southeast Iowa (CPSEI)	83.93	23.16	51.20	172.77	0.28
South Central Illinois (CPILP)	86.21	23.01	52.91	172.83	0.27
Memphis (CPMEM)	90.28	19.47	58.05	160.75	0.22
Soybean Prices					
Mississippi Gulf (SPGF)	210.13	36.53	146.33	297.67	0.17
Illinois Processor (SPILP)	196.98	35.61	141.67	286.67	0.18
Barge Rate					
Average Barge Rate[1] (BR)	9.39	3.06	4.17	18.63	0.33
Rail Rates					
IL – Gulf (RILGF)	9.45	1.69	6.32	17.43	0.18
MN, IA – PNW (RMNPNW)	25.99	2.20	20.26	33.46	0.08
IL – Memphis (RILMEM)	5.86	0.72	4.59	9.64	0.12
Ocean Freight Rates					
Gulf – Japan (OGFJP)	22.62	4.93	12.51	35.47	0.22
PNW – Japan (OPNWJP)	13.57	2.60	9.22	19.99	0.19

[1] It is a weighted average barge rate generated from north Iowa and south Peoria barge rates. It is weighted by the volume of grain moved by barge on the upper Mississippi and Illinois Rivers.

Table 2. Test of Cointegration Among Selected Grain Prices and Transportation Rates.

R	T*	C(5%)*	*D**	T	C(5%)	*D*
= 0	577.32	383.00[**]	R	576.43	367.00[**]	R
# 1	450.29	338.10	R	449.44	323.93	R
# 2	361.69	289.71	R	360.85	276.37	R
# 3	282.99	244.56	R	282.16	232.60	R
# 4	225.32	203.34	R	224.49	192.30	R
# 5	170.76	165.73	R	169.93	155.75	R
# 6	125.39	132.00	F #	124.58	123.04	R
# 7	84.93	101.84	F	84.14	93.92	F
# 8	58.31	75.74	F	57.60	68.68	F
# 9	38.51	53.42	F	38.05	47.21	F
# 10	21.07	34.80	F	20.63	29.38	F
# 11	11.40	19.99	F	11.18	15.34	F
# 12	3.38	9.13	F	3.17	3.84	F

---

[*] The tests results indicated by an asterisk are associated with a constant within the cointegrating vectors. The un-asterisked entries have no constant in the cointegrating vectors, but a constant outside the vectors. The column labeled "D" gives our decision to reject (R) or fail to reject (F), at a 5 per cent level of significance, the null hypothesis of the number of cointegrating vectors (r=0, r ≤ 1, . . . ,r ≤ 12). Following Johansen (1992), we stop testing at the first "F" (failure to reject) when starting at the top of the table and moving sequentially across from left to right and from top to the bottom. The symbol (#) indicates the stopping point.

[**] Extrapolated.

Table 3. Test of Stationarity on Selected Grain Prices and Transportation Rates.

Prices/Rates	Chi-Squared Test	p-value	Decision
Pacific Northwest Corn (CPPNW)	44.12	0.00	R
Mississippi Gulf Corn (CPGF)	44.01	0.00	R
Southeast Iowa Corn (CPSEI)	43.75	0.00	R
South Central Illinois Corn (CPILP)	43.79	0.00	R
Memphis Corn (CPMEM)	44.06	0.00	R
Mississippi Gulf Soybean (SPGF)	44.01	0.00	R
Illinois Processor Soybean (SPILP)	43.96	0.00	R
Average Barge Rate (BR)	44.89	0.00	R
IL – Gulf Rail (RILGF)	44.15	0.00	R
MN, IA – PNW Rail (RMNPNW)	44.38	0.00	R
IL – Memphis Rail (RILMEM)	44.69	0.00	R
Gulf – Japan Shipping (OGFJP)	45.21	0.00	R
PNW – Japan Shipping (OPNWJP)	44.95	0.00	R

Table 4. Test on Exclusion of Selected Grain Prices and Transportation Rates from Cointegration Space.

Prices/Rates	Chi-Squared Test	p-value	Decision
Pacific Northwest Corn (CPPNW)	49.35	0.00	R
Mississippi Gulf Corn (CPGF)	38.64	0.00	R
Southeast Iowa Corn (CPSEI)	46.43	0.00	R
South Central Illinois Corn (CPILP)	19.36	0.00	R
Memphis Corn (CPMEM)	21.79	0.00	R
Mississippi Gulf Soybean (SPGF)	46.49	0.00	R
Illinois Processor Soybean (SPILP)	50.46	0.00	R
Average Barge Rate (BR)	53.99	0.00	R
IL – Gulf Rail (RILGF)	18.40	0.01	R
MN, IA – PNW Rail (RMNPNW)	20.93	0.00	R
IL – Memphis Rail (RILMEM)	12.12	0.06	F
Gulf – Japan Shipping (OGFJP)	37.21	0.00	R
PNW – Japan Shipping (OPNWJP)	17.93	0.01	R

Table 5. Test on Weak Exogeneity of Selected Grain Prices and Transportation Rates.

Prices/Rates	Chi-Squared Test	p-value	Decision
Pacific Northwest Corn (CPPNW)	10.43	0.11	F
Mississippi Gulf Corn (CPGF)	21.24	0.00	R
Southeast Iowa Corn (CPSEI)	27.66	0.00	R
South Central Illinois Corn (CPILP)	19.69	0.00	R
Memphis Corn (CPMEM)	27.94	0.00	R
Mississippi Gulf Soybean (SPGF)	14.13	0.03	R
Illinois Processor Soybean (SPILP)	25.96	0.00	R
Average Barge Rate (BR)	22.10	0.00	R
IL – Gulf Rail (RILGF)	12.57	0.05	R
MN, IA – PNW Rail (RMNPNW)	23.78	0.00	R
IL – Memphis Rail (RILMEM)	20.88	0.00	R
Gulf – Japan Shipping (OGFJP)	8.35	0.27	F
PNW – Japan Shipping (OPNWJP)	26.41	0.00	R

Table 6. Forecast Error Decomposition on Selected Grain Prices and Transportation Rates.

Horizon	BR	CPPNW	CPGF	CPSEI	CPILP	CPMEM	SPGF	SPILP	RILGF	RMNPNW	RILMEM	OGFJP	OPNWJP
							(CPPNW)						
0	0.00	19.49	0.00	0.00	76.47	4.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.43	16.37	0.05	1.21	73.68	2.20	0.06	1.01	0.12	0.79	0.86	2.48	0.74
12	2.66	7.88	0.92	7.03	56.68	13.82	0.02	0.25	0.05	6.30	3.88	0.40	0.11
							(CPGF)						
0	0.08	4.30	21.20	0.51	73.89	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1	0.02	18.05	5.75	0.27	72.14	0.65	0.02	0.28	0.09	0.56	0.34	0.40	1.43
12	3.21	6.95	1.39	5.95	55.46	16.35	0.04	0.26	0.19	6.01	3.59	0.46	0.13
							(CPSEI)						
0	1.15	0.00	0.00	7.56	75.14	15.97	0.00	0.00	0.07	0.02	0.00	0.00	0.07
1	2.37	14.88	0.15	1.87	72.99	2.76	0.02	0.42	0.02	0.35	0.33	2.06	0.02
12	2.24	7.31	0.47	7.09	57.04	13.43	0.03	0.29	0.03	7.06	4.40	0.46	0.13
							(CPILP)						
0	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.14	12.09	0.00	0.05	83.53	0.72	0.10	0.28	0.04	0.54	0.38	0.97	1.16
12	2.84	6.06	0.47	5.70	56.68	15.43	0.04	0.29	0.14	7.55	4.18	0.50	0.12
							(CPMEM)						
0	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	2.01	17.44	0.10	0.01	24.53	48.12	0.06	0.61	0.04	0.77	0.74	3.52	2.05
12	3.26	6.93	0.45	8.59	52.74	9.84	0.38	0.48	0.18	10.20	6.15	0.62	0.17
							(SPGF)						
0	0.00	0.00	0.00	0.00	0.00	28.12	17.55	54.33	0.00	0.00	0.00	0.00	0.00
1	0.00	1.10	0.02	0.82	0.17	34.93	8.38	51.35	0.05	1.66	0.42	0.94	0.15
12	0.34	7.93	0.79	1.93	8.96	8.32	7.63	54.10	1.00	6.03	2.69	0.17	0.10
							(SPILP)						
0	0.00	0.00	0.00	0.00	0.00	34.11	0.00	65.89	0.00	0.00	0.00	0.00	0.00
1	0.13	1.79	0.13	1.31	0.08	30.54	1.11	61.48	0.17	1.86	0.42	0.84	0.17
12	0.28	7.37	0.35	1.92	18.11	3.32	2.72	55.66	0.96	6.25	2.59	0.19	0.96

(continue on next page)

Table 6. Continued.

Horizon	BR	CPPNW	CPGF	CPSEI	CPILP	CPMEM	SPGF	SPILP	RILGF	RMNPNW	RILMEM	OGFJP	OPNWJP
							(BR)						
0	86.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.59	1.72	0.00	0.00	5.83
1	71.58	0.02	1.08	0.16	0.58	4.30	2.68	1.48	4.97	8.50	0.22	0.83	3.61
12	25.08	1.91	11.83	0.31	13.38	3.19	11.65	15.28	12.31	2.85	0.65	0.50	1.05
							(RILGF)						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
1	1.47	0.00	1.82	0.34	1.51	4.20	4.91	0.10	78.51	4.18	0.05	0.17	2.73
12	14.21	1.37	1.37	1.90	7.45	10.78	3.44	3.20	31.12	11.73	2.53	9.65	0.86
							(RMNPNW)						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
1	4.11	0.78	4.66	0.47	0.00	0.54	0.08	0.95	9.16	77.05	0.35	0.14	1.72
12	5.47	11.17	7.81	0.64	5.45	10.28	0.89	0.86	11.44	36.88	6.01	1.68	1.41
							(RILMEM)						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00
1	0.12	4.83	0.05	0.54	11.79	10.56	0.05	1.43	1.81	0.57	63.85	0.08	4.34
12	0.71	8.25	8.32	2.81	7.67	7.09	5.66	8.75	2.18	9.17	34.97	0.73	3.70
							(OGFJP)						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.79	0.00	0.00	68.86	29.34
1	0.72	0.30	0.98	0.05	5.04	8.98	0.06	0.02	3.82	0.04	0.07	55.98	23.95
12	0.45	4.38	1.03	0.31	4.62	1.94	0.12	0.16	7.04	2.60	0.80	58.44	18.09
							(OPNWJP)						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.76	0.00	0.00	0.00	94.24
1	0.63	0.63	1.08	0.15	0.39	1.21	1.95	0.19	9.39	0.05	1.70	3.06	79.58
12	2.94	7.57	1.99	0.31	5.17	1.19	6.13	0.08	17.24	3.55	0.40	9.74	43.71

Figure 1. Directed Acyclic Graph on Innovation from the Error Correction Model Fit to Grain Prices and Transportation Rates, 1992-2001 (Solid lines are found 20% significance level; dotted lines are found at the 15% significance level).

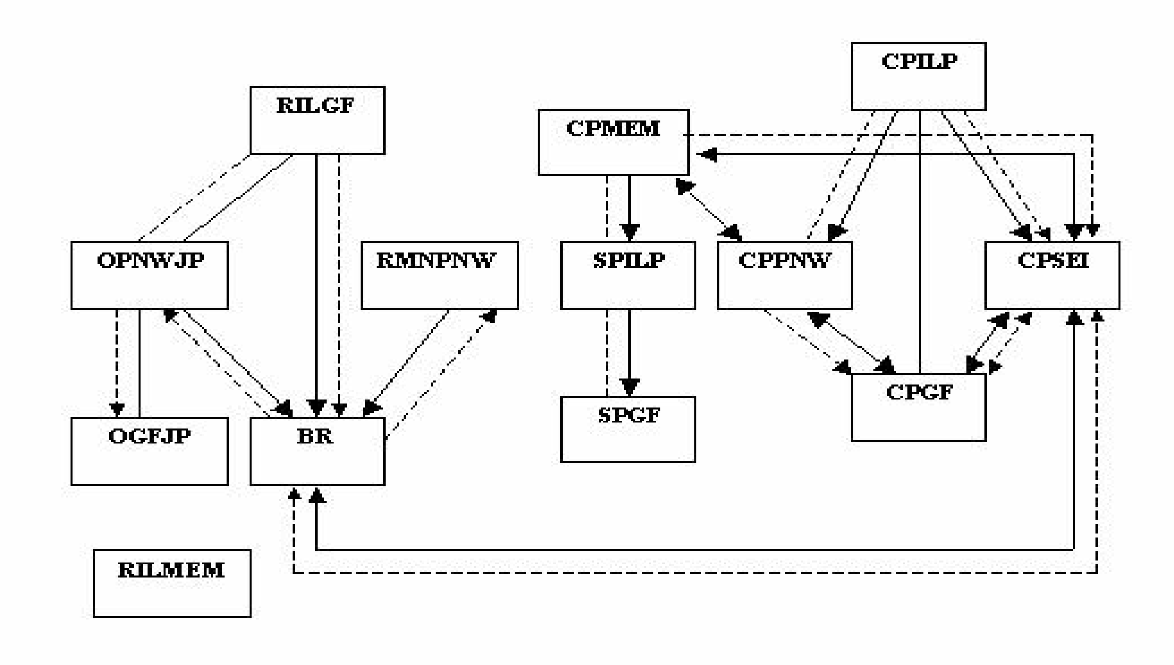

Figure 2. Directed Acyclic Graph with Modifed Schwarz-loss on Pattern Suggested by PC Algorithm in Figure 7.

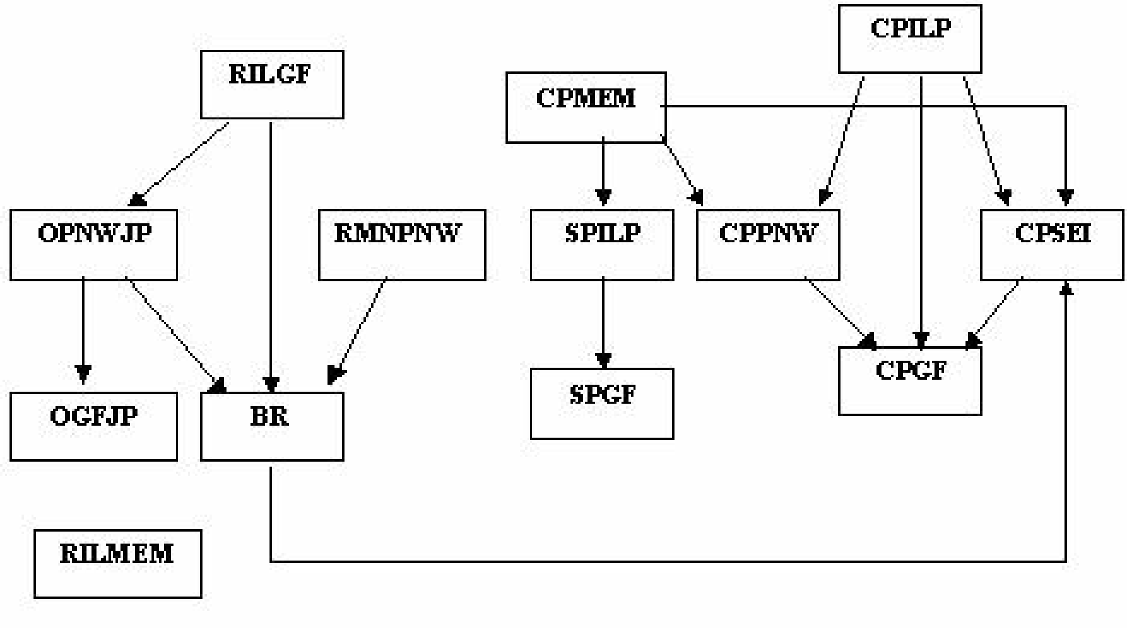

Figure 3. Responses of Each Prices to a One-Time-Only Shock (Innovation) in Each Series, Based on Lagged Relations and Contemporaneous Relations Given in Figure 2.