# ESSAYS ON THE UPPER MISSISSIPPI RIVER AND ILLINOIS WATERWAY AND U.S. GRAIN MARKET

A Dissertation

by

TUN-HSIANG YU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2005

Major Subject: Agricultural Economics

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# ABSTRACT

Essays on the Upper Mississippi River and Illinois Waterway and U.S. Grain Market.

(May 2005)

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This dissertation examines several issues regarding the congestion on the Upper Mississippi River and Illinois Waterway. Chapter II identifies and measures the impact of lock congestion on grain barge rates on these waterways. Results indicate grain barge rates on both rivers are not affected by lagged lock congestion. In present time, however, lock congestion in the lower reaches of the upper Mississippi and Illinois Rivers are found to increase barge rates that link the north central United States to the lower Mississippi Gulf port area. The findings suggest the impact of lock congestion on grain barge rates is moderate.

Chapter III explores the interaction between grain prices in export and domestic markets and transportation rates linking these markets over time. Three model frameworks were evaluated and some consistent results are observed. In general, shocks in transportation rates (barge, rail, and ocean) explain a great proportion of the variation in corn and soybean market prices in the long run, suggesting the importance of transportation in grain price determination. The volatile ocean freight rates are the most

important transportation rates contributing to the variation in grain prices, while shocks in barge rates on the Upper Mississippi River and Illinois Waterway generally explain less than 15 percent of the variation in grain prices. The dynamic interrelationships among the six evaluated transportation rates are also found. In addition, the north central corn markets likely have the most influence over other markets while soybean export price dominates the soybean market in the long run.

Chapter IV estimates the structural demand for grain barge transportation on both the upper Mississippi and Illinois Rivers. Results suggest foreign grain demand is the most influential force affecting grain barge demand on both rivers. Also, results indicate an inelastic demand for grain barge transportation on the Upper Mississippi in the short run; demand is price elastic in the long run. The price elasticity for grain barge demand on the Illinois River is consistently inelastic. Additionally, the winter season and floods affect demand on the Upper Mississippi negatively, while barge demand increases on the Illinois River in winter.

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*Unless the Lord builds the house, its builders labor in vain. Unless the Lord watches over the city, the watchmen stand guard in vain. – Psalms 127:1*

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# TABLE OF CONTENTS

Page

CHAPTER

Page

# LIST OF TABLES

Page

Page

Page

# LIST OF FIGURES

Page

Page

# CHAPTER I

# INTRODUCTION

The United States produces a considerable amount of grain annually in the north central region, which is over a thousand miles from many domestic markets and the principal export ports. Since transportation costs comprise a considerable portion of grain's delivered price as a result of grains' low value-to-weight ratio, a well-developed transportation system is important for efficiently moving grain in the hinterland to domestic and foreign markets. Among all transportation modes, barge transportation is the most economic means to deliver grain from the remote production region to export ports. Currently, most of the export-bound grain is shipped by barge transportation on the Upper Mississippi River and Illinois Waterway to the Mississippi Gulf ports where a significant volume of grain is transited to the international market. The Waterway transports approximately 50 percent of total U.S. corn exports and 40 percent of the Nation's soybeans exports (Brown). In addition to transporting grain down to the lower Mississippi River ports, barges transport farm inputs (fertilizer, petroleum products) upward to the north central U.S. Figure 1.1 presents the historical commodity movement on this Waterway from 1972 to 2002. The agricultural commodities including corn, soybeans, wheat, animal feed, and fertilizer account for about 50 percent

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This dissertation follows the style and format of the *American Journal of Agricultural Economics*.

of the total commercial traffic on this Waterway. Hence this Waterway is an important transportation artery with respect to the U.S. grain industry.

The success of barge transportation on the Upper Mississippi and Illinois Rivers is due to a system of locks and dams designed to maintain adequate water depth for efficient barge traffic. The Upper Mississippi River-Illinois Waterway contains about 1,200 miles of navigable channel and 37 lock and dam sites, with 29 located at 10 to 46 mile intervals on the Upper Mississippi while eight lock sites are located at 5 to 78 mile intervals on the Illinois River (Table 1.1). Currently, the average age of most Upper Mississippi and Illinois River locks exceeds 60 years and because of aging there are maintenance and operation challenges. In addition, the capacity of the lock chambers also creates challenges. Most of these locks were constructed to accommodate tow configurations up to 600 feet in length in the 1930's; however, the current configurations moving on these Rivers are 1,200 feet in length. Therefore, double-lockage is required, which generates a longer transiting and waiting time causing barge delays.

Since the Upper Mississippi and Illinois Rivers are important transport arteries for much of the U.S.'s grain and soybean exports, and lock congestion is prevalent at selected sites, many advocate replacing the 600-foot locks with 1,200-foot locks in the lower reaches of these Rivers. Farm groups particularly argue that anticipated increases in traffic and associated delay on these two Rivers will increase barge operation costs and ultimately barge rates, which will lower the regional prices for grain producers and increase the export prices to foreign buyers. Transportation infrastructure improvements in competitor nations, such as Argentina, Brazil and China, have been accomplished or will be accomplished in the near future and are cited as additional reason for lock capacity expansion on these Rivers. It is argued that these developments may compromise the U.S.'s price advantage and consequently unfavorably influence the competitiveness of U.S. grain in the international market (Rich; Stommes and Brown). Moreover, the failure of the lock system on these Rivers may reduce competition the barge industry provides to the oligopolistic railroad industry, which may also unfavorably affect grain producers in the Midwest (Fellin).

In view of the emerging concerns regarding waterborne transportation on the Upper Mississippi River and Illinois Waterway, a feasibility study for extending selected locks in the waterway to improve navigation efficiency was initiated by the U.S. Army of Corps Engineers in 1993 (USACE, 1997). The Corps proposed to expand five 600-foot long locks (locks 20, 21, 22, 24, 25) on the Upper Mississippi River and locks Peoria and LaGrange on the Illinois River to 1,200 feet, total expenditure exceeding one billion dollars (NAS). Controversies regarding the assumptions and methodologies employed in Corp's study have generated strong debates with respect to the benefits and costs of upgrading those locks. In 2000, the National Academy of Science evaluated the Corps' feasibility study and, unfortunately, concluded this study should be redone due to a considerable amount of flaws observed in the study, such as unrealistic traffic level projection on the waterway, ignorance of the spatial dimension of grain movement, and failure to consider nonstructural strategies for improving congestion (NAS). The Corps is currently revising the study and the debates have yet ceased.

Amazingly, discussions regarding the economics of improving navigation on inland waterways have surfaced in the literature since the early 20th century. Shelton carried out a comprehensive study on a proposed Lakes-to-the-Gulf Deep Waterway project (1912a; 1912b; 1912c; 1914). That inland waterway project was proposed to link Lake Michigan and the Gulf of Mexico through five channels, including the Chicago River, the Chicago Sanitary and Ship Canal, the Des Plaines River, the Illinois River, and the Mississippi River. He compared the boat rates and rail rates for different commodities, including grain, on several portions of the route and found river transportation did not have a lower freight rate. Moreover, the "water-forced" rail rates were not lower than the "free" rail rates because of the river competition. Moulton (1914) questioned the concept of measuring the economic benefits of inland waterway development. In a practical study of the Missouri River, Moulton (1915) argued the improvement of the Missouri River would not generate enough traffic to cover the project costs and the impact of river competition on rail rates would not be observed (pp. 967). Fisher indicated that river transportation was not always less expensive than rail transportation and the issue should be re-visited. He listed several advantages of rail over river transportation and affirmed that development of any inland waterway needs to be carefully examined instead of jumping to a false conclusion based on easy assumptions. Other economists have presented different perspectives of inland waterway improvement. Way compared the rail and barge rates for moving grain and coal from St. Louis to Minnesota, Iowa, Illinois and Tennessee, and suggested the improvements on the Mississippi River will be of great value. Similarly, Titus examined the barge rates for several commodities on the Mississippi River and studied the inland waterway in Europe. He concluded that inland waterway investment will benefit the nation.

Clearly, the development and improvement of infrastructure on the Upper Mississippi River and Illinois Waterway is an issue important to the agricultural and transportation economies. In view of the classic problem regarding the benefits of improving navigation efficiency on the Waterway and the rising concerns regarding the unfavorable influence of lock congestion on the U.S. grain industry, a broader understanding of how lock congestion affects grain transportation and grain markets deserves increased attention. This dissertation aims to contribute toward this understanding.

In Chapter II the author examines whether lock congestion actually affects grain barge rates on the Waterway? If yes, how much is the impact? This is the first step to realizing how lock congestion on the Waterway influences the grain industry. Without knowledge to this information, a measure of economic benefits resulting from lock system improvement is meaningless. The focus of the analysis is lock congestion on segments of the Upper Mississippi River and Illinois Waterway and grain barge rates that link sections of these Rivers to the Mississippi Gulf ports. Multivariate time-series models are employed to explore these questions in combination with directed acyclic graphs.

Chapter III explores how grain barge rates on the Waterway affect export and domestic grain markets and other transportation mode rates, and how the grain prices and transport costs interact over time. This question is interesting since barge transportation on the Waterway primarily serves the export-bound grain that competes with the domestic demand for grain. The interaction of barge rates, grain prices, and other competing/cooperating transportation modes can generate a more comprehensive view of the market channel. Three models with a total of eight grain prices, six transportation rates, and two grain export quantities are evaluated in order to provide a complete analysis. Multivariate time-series mechanisms and directed acyclic graphs are the dual analytical engines in this Chapter.

Chapter IV measures the demand for grain barge transportation for both the Upper Mississippi and Illinois Rivers. Knowledge of grain barge demand on the River is important to the barge industry, grain producers and authorities that maintain and manage the lock system on the River. It is particularly critical today due to the controversies regarding the expansion of the aged lock system on the River. Economic benefits from inland waterway transportation improvements should be based on demand schedules representing the willingness to pay for improved navigability of the waterway. The areas under the demand function measure the gross benefits from waterway improvement. This research provides the first direct estimate of grain barge demand on the Upper Mississippi River and Illinois Waterway. Based on the theory of derived demand for transportation service, a multiple regression analysis is applied to a respective barge demand equation consisting of factors representing excess supply and demand of grain as well as competing/complementary transportation modes for both the

Upper Mississippi and Illinois Rivers. The short-run and long-run price elasticities are obtained.

Chapters II through IV have their own introduction, body, and concluding remarks. The information in each chapter is relative but self-contained. Chapter V provides an overall summary of the conclusions, followed by the Section of References. Tables and figures in each chapter are grouped in the Appendix.

# CHAPTER II

## EFFECT OF LOCK CONGESTION ON GRAIN BARGE RATES ON THE UPPER MISSISSIPPI RIVER AND ILLINOIS WATERWAY

The Upper Mississippi River and Illinois Waterway (UMR-IWW) are important transportation arteries for moving export-destined grain from the U.S. Midwest to lower Mississippi River ports. In addition, the rivers annually carry significant amounts of fertilizer, coal and petroleum products. In 2002, cargo weighing about 127 million tons was transported on the UWR-IWW (USACE/WCSC). Central to navigation on the UWR-IWW are thirty-seven locks and dams that maintain a nine-foot channel for barge transportation. This aging lock and dam system, primarily built in the 1930's, has generated concern about the future navigational efficiency of these transport arteries. Greatest concern centers on lock capacity in the lower portions of these rivers where comparatively high traffic congestion generates extended delays for barges/tows. Grain producers argue that lock delay on the UMR-IWW unfavorably influence barge rates on these transport arteries and consequently the competitiveness of U.S. grain in the international market (Rich). On average, estimated operating costs of a towboat and associated tow of barges operating on the Upper Mississippi River range from $400-$500 per hour (USACE, 2002a; USACE/IWR). Therefore, as tow/vessel delay at selected locks increase, the cost of barging grain on these waterways is expected to correspondingly increase. Further, when barges are demanded for transporting grain from the north-central U.S. to lower Mississippi river ports they cannot be promptly dispatched to the geographic location of demand due to lock congestion, thus a higher barge rate would also be generated. Accordingly, the argument goes, the greater the lock delay that a tow experiences on the UMR-IWW, the higher the barge operator's cost and ultimately the higher the barge rate.

Since the Upper Mississippi and Illinois Rivers are important transport arteries for much of the U.S.'s grain and soybean exports, lock congestion on these rivers is of concern to agricultural interests. In 1993, the U.S. Army Corps of Engineers initiated a feasibility study to determine whether expansion of selected locks in the lower reaches of the UMR-IWW was economically justified (USACE, 1997). Controversies arose regarding methodology and assumptions employed in the economic analysis of this study. In 2000, The National Academy of Science reviewed this study and criticized the Corps for failing to incorporate non-structural alternatives such as scheduling or transferable permits for reducing lock congestion (NAS). Interestingly, one century ago, the improvement of the inland waterway system and the potential impact of barge transportation on the railroad industry and grain traffic had already generated passionate discussions (Fisher; Way; Moulton 1914, 1915; Shelton 1912a, 1912b, 1912c, 1914). Clearly, knowledge of the effects of lock delay on barge rates is central to carrying out meaningful research into the benefits of extending lock capacity. The purpose of this study is to identify and measure the impact of lock delay on grain barge rates. The focus of the analysis is lock delay on segments of the Upper Mississippi and Illinois Rivers and grain barge rates that link sections of these rivers to lower Mississippi River ports. Analyses are carried out following a recently developed suggestion by Swanson and

Granger to model contemporaneous innovation covariance in multivariate time-series models using directed acyclic graphs.

This paper includes a background section that offers perspective of the current lock and dam system and the congestion on the Upper Mississippi and Illinois Rivers. This is followed by a brief literature review and a description of the methodology used to carry out study objectives. A description of data used in the analyses is presented. Finally, results are offered and, then a summary and conclusion are provided.

**Background**

The Upper Mississippi includes twenty-nine lock sites while the Illinois River includes eight lock sites (Figure 2.1). The average age of Upper Mississippi locks is sixty-one years: most locks were constructed during World War II, except for lock 19, Melvin Price lock and lock 27 which were opened in the 1950's and 1990's. These three locks have chambers that are 1,200 feet long while remaining lock chambers are 600 feet or less in length. Most chambers are 110 feet wide. The average age of locks on the Illinois River is sixty-four years with all lock chambers 110 by 600 feet, except one. A barge is typically 195 feet long and thirty-five feet wide, therefore, a 600-foot lock will accommodate, at most, eight jumbo-barges (plus the towboat) in a single lockage while a 1,200 foot lock can accommodate up to fifteen jumbo-barges plus the towboat. Since the number of barges in a tow typically exceeds eight, it becomes necessary to break (cut) tows in order to pass a lock chamber that is 600 feet in length. The break-up and reassembly of the tow (double lockage), plus the hardware operations, takes approximately one hour to ninety minutes at 600-foot locks while passage of towboat and barges at a 1,200-foot lock often requires no more than thirty minutes (Fuller et al., 1998). For this reason, the extension of selected locks in the lower reaches of the Upper Mississippi and Illinois Rivers has been forwarded as a means of reducing lock congestion and associated barge delay.

Tow or vessel delay (wait time) at a lock is defined by the U.S. Army Corps of Engineers as the time elapsed from the arrival of a tow or vessel at a lock to the start of its approach to a lock chamber. Delay includes waiting time experienced while other tows or vessels are being processed and when the lock is stalled or unavailable to perform the locking function. The greatest delay occurs at locks in the lower reaches of the Upper Mississippi River (locks 18 to 25). During the 1980 to 1999 period, lock 22 had the largest average delay per delayed vessel (5.19 hours), while five of the remaining six locks experienced average delays of 2.0 to 4.9 hours, except for lock 19 (Yu and Fuller). Further, if a grain barge traveling from Minneapolis, Minnesota to near St. Louis, Missouri was to be delayed at each lock it would experience an average of fifty-eight hours of delay, with 55% encountered at lock 18 through lock 27. If a grain barge traveling from Chicago, Illinois to near St. Louis, Missouri on the Illinois River was to be delayed at each lock it would experience an average of twenty-seven hours of delay with 57% experienced at the Peoria lock through lock 27 (Figure 1). Among the eight locks on the Illinois River, lock LaGrange had the highest average delay of 3.96 hours during the 1980 to 1999 period. Further, although the average delay time of delayed vessels at each lock on the lower portion of the Upper Mississippi and Illinois Rivers is considerable, there is no obvious trend in average delay except at lock 25 which exhibited a slightly upward trend in delay over the 1980-1999 study period (see Figure 2).

**Literature Review**

Similar to the highway system, congestion on inland waterways has also received great attention in the previous literature. Rao studied the optimization of navigation investments to reduce lock congestion on inland waterway. A branch-and-bound method was developed to determine which locks on the Upper Mississippi River and Illinois Waterway to improve and the sequence of improvement. It was concluded that nonstructural means of increasing lock capacity are the most efficient option in the short run. Rao shows that the economic feasibility of structural alternatives depends mainly on the timing of investments, the traffic forecasts and the fleet composition. Wilson evaluated the performance of two queueing models, M/M/1 and M/G/1, as means of simulating lock congestion. The M/G/1 model was found to perform adequately for the operation of most single-chamber locks and predict delays well, while the M/M/1 did not generate satisfactory results. Martinelli and Schonfeld criticized previous inland waterway congestion studies because each lock was treated as an independent facility. A microsimulation model was developed by Martinelli and Schonfeld that incorporate lock interdependence when calculating lock delays. They believed it to be capable of generating a more comprehensive assessment of benefits that result from lock system improvement. Ting and Schonfeld (1996) used heuristic methods to evaluate the time saving associated with different sequencing algorithms when locking towboats on inland waterways. Two algorithms were introduced, the shortest processing-time first (SPF) algorithm that gives priority to tows with shorter processing times, and the maximum saving (SAVE) algorithm that favors tows with the highest relative advantage at particular chambers. Results showed that when compared with the traditional first-come-first-serve (FCFS) operation, the projected delay savings of applying the SPF and SAVE methods to the congested locks was 79.73% and 75.85%, respectively. Dai and Schonfeld pointed out the difficulties of estimating delays for a lock queueing system, including complex arrival and service time distributions, dissimilar parallel chambers, various chamber assignment disciplines, considerable interdependence among a series of locks, two-way traffic through bi-directional chambers, and stalls. They argued that pure queueing models are not appropriate to estimate lock delays and developed a metamodelling approach to approximate the results of the simulation model. The results of the numerical method were shown to be close to the simulation outcomes. Ting and Schonfeld (1998) integrated the control algorithm and lock interdependence into their simulation to evaluate the delays at locks. Their findings suggested an integrated control algorithm could yield lower cost per barge. Lave and DeSalvo conducted a study to examine the optimal use of a locking system, when to expand lock capacity, and the effect of a toll on the character of the service demanded while congestion occurs. The authors used the Illinois River to demonstrate the benefits and costs of infrastructure expansion and the optimal toll. Case and Lave discussed the criteria for evaluating waterway user charges and argued for a combination of toll schemes, including segment tolls, locking fees, and congestion tolls. They believe such a scheme to be economically and politically feasible and to surpass fuel taxes and license fees as means of generating revenues. Case and Lave applied their methodology to the Illinois River to illustrate the predictive power of the developed model.

Since the grain industry is the primary barge transportation customer, the impact of lock delays on the grain industry has emerged as an important inland waterway topic. Fuller and Grant used spatial models to evaluate the effect of projected lock delay in 2020 on the efficiency of marketing north central U.S.'s corn and soybean production via the Upper Mississippi and Illinois waterways. They project annual cost of marketing corn and soybean production in the north central region in 2020 to increase by $22.54 million above that projected for 2000 if lock capacity is unchanged. The increased cost of barging on the Upper Mississippi and Illinois Rivers redirects grain to less efficient transportation modes, thus increasing total marketing costs. Jack Faucett Associates (JFA, 1997) estimated for the U.S. Army Corps of Engineers that corn and soybean traffic will double on the Upper Mississippi and Illinois Rivers over the 1995 to 2045 period, therefore, the expansion of some key locks should be considered. More recently, JFA (2000) lowered their projection of grain exports and waterway traffic since their earlier analysis was criticized as over-estimating likely traffic levels. Further, their analysis failed to include some important dimensions such as destinations other than the lower Mississippi River ports or other uses for the grain (Bitzan and Tolliver). A National Academy of Science study criticized the Corps for proposing an expensive lock expansion program as the only solution to increased traffic volume and delay (NAS). The nonstructural alternatives, such as better-trained deck hands, powered devices to reassemble tows, and scheduling of towboat arrival, were suggested to be investigated with respect to their feasibility by the National Academy of Science to reduce lock delay rather than the expensive lock expansion projects proposed by the Corps. Fellin et al. used spatial grain models (quadratic programming models) to illustrate their use in estimating benefits from inland waterway navigation improvements. The illustrated methodology appears to circumvent some of the criticism directed at similar analyses by the Corps. Gervais et al. used a disaggregated linear programming model, to evaluate the short-run economic impacts of Upper Mississippi River navigation improvements. They show expanding critical locks (locks 20, 21, 22, 24 and 25) to 1,200 feet on the Upper Mississippi River would provide limited benefits for Iowa grain producers.

## Methods for Analysis

In this study, multivariate time-series analysis is employed to measure the lagged relationships among analyzing factors while directed acyclic graphs (DAGs) methodology is adopted to identify the contemporaneous causality among evaluated series.

### *Vector Autoregression (VAR) Analysis*

To efficiently examine the relationships among a set of N economics variables, a vector autoregression (VAR) representation is quite useful (Enders). With a VAR, the set of variables involved in the interaction and the maximum length of lags needed to capture most of the effects on each other should be specified (Pindyck and Rubinfeld). The VAR($p$) model including $p$ lags is written (Griffiths et al.):

(2.1) $y_t = \delta + \Phi_1 y_{t-1} + \Phi_2 y_{t-2} + ... + \Phi_p y_{t-p} + e_t$

where

(2.2) $y_t = \begin{bmatrix} y_{t1} \\ y_{t2} \\ \vdots \\ y_{tN} \end{bmatrix}; \quad \delta = \begin{bmatrix} \delta_{t1} \\ \delta_{t2} \\ \vdots \\ \delta_{tN} \end{bmatrix}; \quad \Phi_i = \begin{bmatrix} \phi_{i11} & \phi_{i12} & \cdots & \phi_{i1N} \\ \phi_{i21} & \ddots & & \vdots \\ \vdots & & \ddots & \vdots \\ \phi_{iN1} & \cdots & \cdots & \phi_{iNN} \end{bmatrix}; \quad e_t = \begin{bmatrix} e_{t1} \\ e_{t2} \\ \vdots \\ e_{tN} \end{bmatrix}.$

$\delta$ is a (Nx1) constant matrix while $\Phi_i$ is a (NxN) coefficient matrix associated with each lag term ($i$=1,…, $p$) of N variables, and $e_t$ is a matrix of error (innovation) terms. Equation (2.1) indicates that each of the N variables is a function of $p$ lags of all N variables, including itself, a constant and a present innovation (error) term. The unknown parameter matrices Φ and δ can be estimated via ordinary least squares, as efficient estimation derives from the same set of regressors in each equation (Sims).

Individual coefficients of the VAR are difficult to interpret. Under such cases, innovation accounting which summarizes the moving average representation (MAR) of the estimated VAR may be the best description of the dynamic structure (Sims; Swanson and Granger). We estimate the parameters of equation (2.1) using ordinary least squares regression (Sims) and then invert the estimated VAR to its moving average representation. We then conduct innovation accounting based on the MAR to summarize the dynamic interactions among evaluated series.

Analysis of equation (2.1), without making some adjustment for non-orthogonal contemporaneous innovations, may not reflect the historical patterns present in the data (see Sims). We prefer to work with a transformed moving average representation on orthogonalized innovations $v_t = Ae_t$, where A is such that $E\{v_t v_t'\} = D$, and D is a diagonal matrix. Researchers employing VAR models have traditionally used a Choleski factorization of the (contemporaneous) innovation correlation matrix to provide a Wold causal chain on how an innovation in series *i* reacts to an innovation in series *j* in contemporaneous time. The Choleski factorization is recursive and may not reflect the "true" causal patterns among a set of contemporaneous innovations. More recently, researchers have followed the structural factorization commonly referred to as the "Bernanke ordering" (Bernanke) which requires writing the innovation vector ($e_t$) from the estimated VAR model as, $e_t = A^{-1}v_t$, where A is a matrix of order NxN and $v_t$ is a Nx1 vector of orthogonal shocks.

While the Bernanke ordering allows one to move away from the mechanically imposed constraint of recursive causal ordering embedded in the Choleski factorization, it requires researchers to actually specify a contemporaneous causal pattern among current period innovations. In this study we have little information for specifying the ordering in a Choleski factorization. Accordingly, we abandon any attempt to solve the causality in current time question with a Choleski factorization of contemporaneous covariance.

Here we apply directed graph algorithms (see the discussion given below) to place zeros in the A matrix (e.g. $v_t = Ae_t$). Directed graphs have recently been used in the literature for just this purpose in similar settings (Swanson and Granger; Bessler and Fuller, 2000; Hoover).

Given equation (2.1) we can write vector $y$ in terms of orthogonalized innovations as follows:

$$(2.3) \quad y_t = \sum_{i=0}^{\infty} \Theta_i v_{t-i}$$

Here the vector $y$ is written as an infinite combination of orthogonalized innovations, $v_{t-i}$. The moving average parameters, $\Theta_i$, can be calculated for any distance into the past through the zero/one simulation of the autoregressive version of this model (equation 2.1).

We use recent innovations in graph theory and PC algorithm (described below) to determine the causal pattern behind the correlation in contemporaneous innovations ($\Sigma = E\{e_t e_t^{'}\}$) and to construct orthogonal innovations (($D = E\{v_t v_t^{'}\}$).

***Directed Acyclic Graphs (DAGs)***

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. An idea upon which our analysis is based is that causal chains (A→ B→C), causal inverted forks (A→B←C), and causal forks (A←B→C) imply particular correlation and partial correlation structures between and among the measures A, B, and C. 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.

Sprites, Glymour and Scheines developed PC algorithm to infer causal relations from observational data. PC (the name refers to the first initial of each author's first name P(eter) Spirtes and C(lark) Glymour) algorithm utilizes a step-wise procedure beginning with a general unrestricted set of relationships among variables. It begins with a complete undirected graph – where every variable is connected to every other variable, without directions (arrows). It removes connections or edges (lines) between variables based on zero correlations or conditional correlations. That is, if a correlation or conditional correlation between two variables is not significantly different from zero, the edge (line) between them is removed. After considering all edges and all possible sets of conditioning variables (other variables) the final set of edges (those not removed) are directed. The notion of a "sepset" is used to carry-out this directional step. *The conditioning variable(s) on removed lines between two variables is called the sepset of the variables whose edge has been removed (for vanishing zero-order conditioning information the sepset is the empty set).* Suppose we have three variables A, B and C: directed edges between triples A – B – C appear as A → B ← C if B is not in the sepset of A and C. Further, if A → B, B and C are adjacent, A and C are not adjacent, and there is no arrowhead at B, then B – C is oriented as B → C. If there is a directed path from A to B and an edge between A and B, then orient A – B as A → B.

Fisher's *z* (Spirtes, Glymour and Scheines, p. 94) is used to test whether conditional correlations are significantly different from zero, where

(2.4) $Z[\rho(I, J|K)N] = ½(N - |K| - 3)^{1/2} \times LN[|1+ \rho(I, J|K)| \times (|1 - \rho(I, J|K)^{-1}]$

and, *n* is the number of observations, $\rho(i, j|k)$ is the population correlation between series *i* and *j* conditional on series *k*, and |*k*| is the number of variables in *k* (that we condition on). If *i*, *j* and *k* are normally distributed and $r(i, j|k)$ is the sample conditional correlation of *i* and *j* given *k*, then the distribution of $z[\rho(i, j|k)n] - z[r(i, j|k)n]$ is standard normal. The software TETRAD is developed to process the PC algorithm and its extensions (Scheines et al.).

The directed graph methodology can complement the function of "Granger" causality for the purpose of this study. Granger causality is suitable for analysis of a time sequence in causal systems. As an example, Granger causality would be appropriate in the study of a lagged relationship between two variables, say $x_1$ and $x_2$: $x_{1t} = a_{10} + a_{11} x_{1,t-1} + a_{12} x_{2,t-1} + e_{1t,}$, where $x_{1,t-1}$ and $x_{2,t-1}$ are observations on variables $x_1$ and $x_2$ observed in period t-1, $a_{10},$ $a_{11}$ and $a_{12}$ are unknown parameters to be estimated with observed data and $e_{1t,}$ is a *white noise* disturbance term. Here if $x_1$ and $x_2$ and their lags are a causally sufficient set of variables (there are no omitted (hidden or latent) variables that cause both $x_1$ and $x_2$ and the world is well-modeled as linear) a non-zero estimate of $a_{12}$ would allow us to say $x_2$ causes $x_1$ in Granger's sense. However, Granger causality is not appropriate when the dependent variable and the independent variables have a contemporaneous relationship.

### *Theory and DAG Representations*

A basic assumption of the directed acyclic analysis, as well as an implicit assumption on many other analyses of observational data, is that there are no omitted or hidden variables that cause any two variables included in the study. The assumption is not that there are no omitted variables for say A, B, and C, if we would like to evaluate the causal relation between A and B. Rather, *there is no omitted variable, say D, which causes both A and B.* Researchers using experimental data, where treatments (A, B, or C) are assigned using random assignment, have no need for such an assumption, as random assignment effectively deals with the omitted variable problem. In work with observational data, we are required to make such an assumption and consequently any results are offered with caution, as the possibility of one or more omitted variables is never remote (see Spirtes et. al., for a discussion of experimental design, DAGs and causal inference on observational data.)

Theory suggests barge rates are determined by the intersection of barge demand and supply curves (see Figure 2.3). The demand for grain barge transportation is a derived demand generated from the excess supply and demand of grain in the origin and destination markets. Therefore, any factors shifting the excess supply and demand curves of grain can ultimately affect the demand for grain barge transportation. Similarly, factors shifting grain barge transportation supply can also affect the barge rate. Intuitively, those demand and supply shifters of grain barge transportation should be included if we are to estimate a grain barge rate equation (an equation explaining the movement of grain barge rates). However, the objective of this study is specifically to evaluate and measure the impact of lock delay (variable B) on grain barge rates (variable A). If one is interested in estimating the effect of one variable (lock delay) on another variable (barge rates) he/she does not need to include all variables that cause the latter (barge rates) in the equation. Rather, he/she needs only to include covariates that cause both the variables of interest (lock delay and barge rates). Omitting some demand or supply shifters will not generate a biased estimate of lock congestion on grain barge rates as long as the demand and supply shifters do not affect *both* barge rate and lock delay (see Pearl, p. 78-84 and 355-56 for a discussion of the "adjustment for covariates").

Figure 2.4 depicts a relationship between grain barge rates and those likely factors influencing barge rates. Variables on the top portion of the figure are shifters of barge supply that, include lock delay, crew wages, fuel prices, and so on. Obviously, while lock delay increases, or crew wages and fuel prices move upward, the cost of operating barge transportation will increase and thus ultimately will create pressures to increase barge rates. Demand shifters, located in the lower portion of the figure, include corn production at origins (the Midwest), corn prices at the existing port (Mississippi Gulf), alternative transportation rates (rail rates), exchange rates, and so forth. Demand factors will affect the quantity of grain transported by barge on the River, i.e. the traffic level on the River, and ultimately influence the barge rates. Except for the traffic level variable, we believe the other demand or supply shifters will not affect both grain barge rates and lock delay directly[1]. Excluding those variables will not generate a biased estimate regarding the effect of lock delay on grain barge rates.

**Data**

To study the effect of lock delay on grain barge rates, accumulated lock delay for locks on selected segments of the Upper Mississippi and Illinois Rivers were obtained from the Corps' Lock Performance Monitoring System (LPMS) data set. Monthly average delay of tow vessels for locks located on various river segments were aggregated and included in the analysis. For simplification purposes, it is necessary to group lock delays on river segments since it was computationally impossible to include all locks in the estimation system due to the large number of locks on both rivers. Moreover, accommodating seasonal factors in analysis is another crucial reason for grouping lock delays, especially for the Upper Mississippi River. The grain harvest, typically a peak shipment period, moves geographically from south to north during the fall. Harvest tends to peak earlier in the southern portion of the study region (Missouri) than northern portion (Minnesota). Thus, it was deemed important to accommodate by grouping

[1] Grain Barge Volume on the River and Grain Barge Rates may be simultaneously determined and thus a two way arrow would apply in Figure 2.4 between these two variables. The author tested for endogeneity of barge numbers (as a proxy for the unavailable measure on grain barge volume) in a barge rate equation using a Hausman test for endogeneity (Wooldridge (2002)). Since Japan is a primary importing country of U.S. grain, the exchange rate of Japanese Yen to U.S. dollar is a good candidate as an instrument for the grain quantity moved by barge on the River. For this instrument, the hypothesis of endogeneity of total barge numbers is rejected at the 5 percent significance level. Alternatively, the author demonstrates in the empirical section of this paper (see Table 2.5 below) that Grain Barge Rates do affect Barge Numbers at lags.

contiguous locks in various portions of the river. Further, the navigability of the river in the late fall (river closing) and early winter (river opening) is dissimilar on the various segments. For example, in the lower reaches of the Upper Mississippi (Keokuk to St. Louis) the river may not freeze during some winters, while in the Iowa portion of the river the opening and closing dates may be different than those on the Minnesota segment. For these reasons, locks were grouped largely to accommodate seasonal forces. For analyses of the Upper Mississippi barge rates, lock delay on the following segments were included: (1) lock 1 to lock 8 (L1_L8), (2) lock 9 to lock 17 (L9_L17), and (3) lock 18 to lock 27 (L18_L27). For the Illinois River barge rate, lock delay on the following segments were included into the analysis: (1) Thomas O'Brien lock to Starved Rock lock (TOB_SR), (2) Peoria lock and LaGrange lock (PEO_LA), and (3) Melvin Price lock (LMP) and lock 27 (LMP_L27) (Figure 2.1). See Table 2.1 for descriptive statistics on average accumulated lock delay for vessels traversing various segments of the Upper Mississippi and Illinois Rivers.

In general, approximately two-thirds of the Upper Mississippi River traffic is down-bound with grain comprising about 85% of this movement and about half of all commerce on the river. Virtually all grain entering the Upper Mississippi is destined for lower Mississippi River ports. About 40% of the grain moving on the Upper Mississippi enters in the Minnesota portion of the river, 50% in the Iowa segment, and 10% in the Missouri portion. Traffic tends to be light in the Upper reaches but comparatively great in the lower reaches of the River as the density of down-bound traffic levels grow. As a result, lock congestion and associated tow delay at locks 18 to 27 on the Upper

Mississippi is the greatest of any segment (Table 2.1). During the 179 navigable months between the years 1980-1999, the average delay incurred by tows traversing locks 18 to 27 was 29.08 hours, while average delay at locks 1 to 8, and locks 9 to 17 was 6.97 and 13.05 hours (Table 2.1). For a tow traveling the entire length of the River (Minneapolis to St. Louis) and experiencing delay at each lock, expected delay during the study period was 49.10 hours (29.08 + 13.05 + 6.97 = 49.10 hours).

Barge rates were from the Agricultural Marketing Service of the U.S. Department of Agriculture (USDA/AMS, 2001). They collect spot barge rates from Midwest barge companies (or brokers). According to Harnish and Dunn, privately-negotiated long-term and spot contracts account for about 80% of the total grain barge hauls, while "No Price Established" contracts, a special type of long-term contract, represent 30-40% of grain barge transaction. These contracts specify the quantity and location of shipment, but the freight rate will be negotiated in advance of loading. We believe the negotiated rate will be closely related to the spot rate. One may argue that the spot rate only represents a limited portion of grain barge transactions; however, Binkley and Bessler found the spot rates generally lead the price behavior of the long-term contract rates in the ocean freight market which is probably similar to the barge industry. Moreover, the long-term contract rates are not available publicly. The only available rate for study is the spot rate, which is generally employed in grain barge studies (Harnish and Dunn; Miljkovic et. al.). The spot rate is the current barge rate for shipping grain from river segments to export facilities located on the lower Mississippi River. The spot rate does not reflect any discounts, promotions or contracted services.

Grain barge rates that link segments of the Upper Mississippi and Illinois River to lower Mississippi River ports were collected for the analysis. Barge rate data was obtained for the following river segments: (1) south Minnesota (BRSM), (2) north Iowa (BRNI) on the Upper Mississippi, and (3) south of Peoria (BRSP) for Illinois River grain shipments. South Minnesota rates are representative of the St. Paul, Minnesota to McGregor, Iowa segment of the Upper Mississippi while north Iowa includes the segment extending from McGregor, Iowa to Clinton, Iowa (Table 2.1). Grain barge rates were not evaluated during the winter season (December, January and February) and in July 1993 due to a flood on the Upper Mississippi, whereas rates on the Illinois River were available year-round. A total of 179 monthly barge rates were collected for each segment of the Upper Mississippi River and 240 monthly barge rates were obtained for the Illinois River.

The most suitable variable to measure grain traffic level would be the quantity of grain moved by barge on the Upper Mississippi River and Illinois Waterway. Unfortunately, these data are only accessible from 1990 to 1999. As a consequence, we selected the overall number of barges (loaded and empty) passing through lock 25 (TOTBG25) and the LaGrange lock (TOTBGLA) as the Upper Mississippi and Illinois Rivers respective traffic levels. Lock 25 is a high volume lock at the lower reaches of the Upper Mississippi since it is transited by all commerce entering and exiting the Upper Mississippi, while the LaGrange lock handled all traffic flows entering and exiting the Illinois River (Figure 2.1). This total number of barges passing a lock, a proxy of traffic level on the river, was obtained from the Corps' Lock Performance

Monitoring System (LPMS) data set. As expected, the grain traffic level at lock 25 (Mississippi River) is significantly higher than at the LaGrange lock (Illinois River) (Table 2.1). This results from higher grain production in Iowa and Minnesota.

**Results**

In this section, the time series properties of the data and the directed acyclic graph analysis for both Upper Mississippi and Illinois Rivers are offered. The influence of lock congestion on grain barge rates is also measured. In addition, the impulse response analysis and forecast error variance decompositions of the evaluated series are included.

We apply the Vector Autoregression (VAR) analysis to explore the relationship between grain barge rates, accumulated average lock delay of vessels on segments, and traffic level on the River. For the Upper Mississippi River, the southern Minnesota (BRSM), and the north Iowa (BRNI) grain barge rates are selected, while the total number of barges passing through lock 25 (TOTBG25) is used as a proxy of traffic levels. The three segments are lock 1 to lock 8 (L1_L8), lock 9 to lock 17 (L9_L17), and lock 18 to lock 27 (L18_L27). With respect to the Illinois River, the south Peoria barge rate (BRSP) and the total number of barges passing through the LaGrange lock (TOTBGLA) are included in the analysis. The lock delays are grouped into three segments: (1) Thomas O'Brien lock to Starved Rock lock (TOB_SR), (2) Peoria lock to LaGrange lock (PEO_LA), and (3) Melvin Price lock to lock 27 (LMP_L27). We include the Melvin Price lock and lock 27 on the Upper Mississippi River in the analysis of south Peoria barge rates (BRSP) since we believe the delay at those two Mississippi

River locks may also affect the availability of barges on the Illinois River, and consequently the grain barge rate.

Prior to the VAR analysis, it is necessary to determine if each series is stationary. Table 2.2 relates Augmented Dickey-Fuller test results regarding the null hypothesis of non-stationarity of each series for both rivers. All six variables for the Upper Mississippi River as well as the five variables for the Illinois River were found to be stationary, since the t-statistics are less than the 5% critical value (-2.89).

Given that these time series variables are stationary, it is plausible to continue the VAR analysis. Table 2.3 summarizes Schwartz Loss and Hannan and Quinn Φ measures in determining lag lengths for the VAR equation of both rivers. In the test for the Upper Mississippi River, we include eight monthly indicator variables in each VAR equation to account for seasonality since we drop the non-navigable season (December, January, and February); while eleven monthly indicators are added in the Illinois River system because the Illinois River is generally navigable year round. We search over lags of zero (a constant plus seasonal dummy variables) through five periods and conclude a VAR of one lag is appropriate for both the Upper Mississippi and Illinois Rivers.

The estimated VAR model is not reported here since it is recognized that individual coefficient estimates are difficult to interpret (Sims). *F*-tests, however, are reported in Table 2.4 (in this case, since we have only one lag, we could have reported t-statistics; generally research workers report the F-test as multiple lags are often present in Granger-type causality analysis to present the influence of each lagged variable on the individual series (Granger). The dependent variable is listed on the headline while the first-column is the lagged term of each variable as explanatory variables.  For the Upper Mississippi River, barge rates (BRSM, BRNI) are not affected by lagged lock delays (L18_L27, L9_L17, L1_L8) at the 5% significance level, nor does the lag in overall traffic level (TOTBG25) affect barge rates.  A barge rate (BRSM, BRNI), as expected, is influenced by the other barge rate's lagged term.  Lock delays are primarily affected by their own lagged information, while traffic levels (TOTBG25) are influenced by the lagged Iowa barge rate (BRNI), lagged delay at locks 18 to 27 (L18_L27) and at locks 1 to 8 (L1_L8), and its own lagged information.  Similarly, the Illinois River barge rate (BRSP) is not affected by the lagged lock delay (TOB_SR, PEO_LA, L26_L27) information.

The innovations generated from the VAR model may be the best description of the dynamic structure (Sims; Swanson and Granger).  The contemporaneous structure of interrelationships among grain barge rates, lock delays, and traffic levels may be explored by applying directed acyclic graph (DAGs) analysis to the variance-covariance matrix of residuals from the VAR.  A Bernanke ordering may be used with the discovered structure by the DAGs on the contemporaneous configuration (Bernanke).

In the case of the Upper Mississippi River, the DAGs results on the innovations are presented in Figure 2.5.  The directed graph analysis shows traffic levels at lock 25 (TOTBG25) cause accumulated monthly lock delay at lock 18 to lock 27 (L18_L27), which directly causes the grain barge rate that links the south Minnesota portion of the Upper Mississippi to New Orleans (BRSM) and ultimately affects the grain barge rate of north Iowa to New Orleans (BRNI) in the contemporaneous time period (Figure 2.5 and

Table 2.2)[2]. Hence, lock delay in the most congested portion of the Upper Mississippi partially causes the Minnesota barge rate in present time period. Traffic levels at lock 25 also cause lock delay at lock 9 to lock 17 (L9_L17), which has an indirect relationship with the south Minnesota barge rate. The association between delay at lock 18 to 27 and at lock 9 to 17 is found, however, the statistical strength of the relationship is not adequate to infer causality. As discussed in the Data section, due to the impact of seasonality on marketing and transportation of grain on various river segments, it is not obvious that delay at locks 1-8 or 9-17 should cause delay at 18-27. Figure 2.6 illustrates the directed graph generated from the residuals of the Illinois River's VAR model. Results show that the Illinois River barge rate (BRSP) is caused by accumulated barge delay at the Peoria and LaGrange locks (PEO_LA), Melvin Price lock and lock 27 (LMP_L27) and the total number of barges transiting the LaGrange lock (TOTBGLA) in the contemporaneous time.

Following the general model described in equation 2.3, we can summarize the dynamic patterns in our VAR using two forms of innovation accounting (Sims). The

[2] As stated in the Methodology section, ignoring a variable that causes two other variables with observational data may generate a biased estimate of a relationship. To demonstrate the discovered causal relationship between lock delay and barge rate will not be removed with an additional variable in the model, we include a supply shifter of barge transportation, diesel price, in the analysis and generate a new directed graph. Results showed the causality between lock delay and barge rate still holds. Also, we include a demand shifter, export corn price, in the analysis and obtain the similar results. Of course many other possibilities for omitted variables may be considered, but with these two prime candidates as possible omitted variables, we see no changes from the results reported in Figures 2.5 and 2.6. Excluding variables that do not cause both lock delays and barge rates will not generate a biased estimate of the relationship between lock delay and barge rate.

impulse response functions summarize the dynamic response of each series following a one-time-only shock in each series. In the impulse response analysis of the Upper Mississippi River, we found about 2.83¢ per ton increase in the Minnesota grain barge rate (BRSM) given a positive shock on the delay at locks 18 to 27, i.e. an additional hour of accumulated delay at locks 18 to 27 will increase the Minnesota barge rate 2.83¢ per ton. The average delay time of all vessels on this segment is 29.08 hours (Table 2.1), therefore, the average cost of delay is about $0.79 per ton (29.08 x 2.83¢ per ton)[3] or about $1,232 per barge, assuming each barge carries 1,500 tons of grain. Similarly, based on the impulse response function, Iowa grain barge rate will increase 2.14¢ per ton resulting from an additional hour of accumulated delay at locks 18 to 27. Since the accumulated average vessel delay at locks 18 through 27 is 29.08 hours, the delay at these locks adds, on average, about $0.62 per ton to the Iowa grain barge rate or about $934 per barge.

Figure 2.7 offers an illustration of the impulse response functions for grain barge rates, lock delays and traffic volumes to each other on the Upper Mississippi River[4]. Each row of the figure depicts the dynamic response of one series to a one-time-only shock in the other variables listed at the heading of each column. These shocks are

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[3] The functional form of the underlying marginal cost curve is unknown; we assume it is constant over the study range. Of course, textbook forms do not have a constant slope on the marginal cost function, thus our results are an approximation.

[4] The purpose of this figure is to offer a sense of the response from viewing the overall pattern in one graph.

presumably the new information originating for that series. The responses are normalized by dividing each response by the historical standard deviation of the innovation in each series. Basically, this figure indicates that a one-time-only shock in delay at locks 18 to 27 (L18_L27) will increase barge rates of Minnesota (BRSM) and Iowa (BRNI), and the impact will diminish to zero after six or seven time periods (the third and fourth columns). Delay at other segments on the Upper Mississippi (L9_L17, L1_L8) has a comparatively modest influence on barge rates. In addition, the expected positive response of lock delay to a one-time-only shock in traffic at lock 25 (TOTBG25) is observed (the last column).

The impulse function associated with Illinois River grain barge rates shows that an additional hour of accumulated delay at the Peoria and LaGrange locks (PEO_LA) add 2.55¢ per ton to the south of Peoria barge rate while an additional hour of delay at the Melvin Price lock and lock 27 (LMP_L27) add about 2.58¢ per ton. Historically, lock delay at the Peoria and LaGrange locks averaged about 6.32 hours (Table 2.1): based on the estimated impulse response, delay at these locks adds about $0.16 per ton to the Illinois River barge rates. Delay at the Melvin Price lock and lock 27 (LMP_L27) also increases the Illinois River barge rates about $0.22 per ton. Delay on both river segments increase the Illinois River barge rates about $0.39 per ton or $580 per barge.

The impulse response function for grain barge rates, lock delays and traffic levels on the Illinois River is presented in Figure 2.8. Illinois River grain barge rates (BRSP) primarily respond to the shock in delay at the Peoria and LaGrange locks (PEO_LA) and the Melvin Price lock and lock 27 (LMP_L27) in the Figure 8 (the first row). Lock delays on the relatively congested segment (PEO_LA, LMP_L17) exhibit positive responses to the shock in Illinois River traffic levels (TOTBGLA) (the last column).

Forecast error variance decompositions offer an alternative view of the dynamic patterns captured in the VAR. Here we explore what percentage of the forecast error variance at a particular time horizon is accounted for by past innovations in each VAR series (Sims; Franses). Table 2.6 summarizes the forecast error variance decompositions on barge rates, lock delays, and traffic levels on the Upper Mississippi River. The column headed "Horizon" represents time horizon at zero, one and nine months ahead. The sum of each row is 100%. For example, for Minnesota barge rates (BRSM), the uncertainty associated with current rates is primarily explained by current period shocks in its own price (94.16%), and shocks in delays at locks 18 to 27 (L18_L27) (5.45%). When we move to one period (one month) ahead, the uncertainty in BRSM is again primarily affected by itself (89.64%). However, the Iowa barge rate (BRNI) begins to exhibit influence on the Minnesota barge rate at the one-month horizon. Meanwhile, the influence of delay at locks 18 to 27 is now stronger (6.65%). At the extended horizon of nine months ahead (equivalent to one year since the Upper Mississippi River is generally navigable nine months), Minnesota barge rates are explained by innovations in lock delay at locks 18 to 27 by about 6.53%; while nearly 7% (6.53+0.35+0.28 = 7.16) of its forecast uncertainty (variance) is explained by innovations in delays on all three segments (L18_L27, L9_L17, and L1_L8). Similarly, in the contemporary period (at horizon 0), an estimated 67.16% of the variation in the Iowa barge rate (BRNI) is explained by shocks in the Minnesota barge rates (BRSM), 28.67% by shocks in itself, and 3.89% by shocks in the delay at locks 18 to 27 (L18_L27). At a horizon of nine months, the portion of variation in Iowa barge rates explained by lock delay at locks 18 to 27 increases to 5.09%, while Minnesota barge rates continues to have a dominating influence on the Iowa barge rates (72.96%).

Variation in lock delay variables (L18_L27, L9_L18, L1_L8) is primarily explained by shocks in itself in the contemporary period and in the long run (Table 2.5). However, at a nine-month horizon, shocks in river traffic levels (TOTBG25) explain the variation in delay at locks 18 to 27 (L18_L27) and at locks 9 to 17 (L9_L17), 13.33% and 15.92%, respectively. In contemporaneous time, variation in River traffic level (TOTBG25) is exogenous. At a nine-month time horizon, the two barge rates (BRSM and BRNI) in aggregate account for about 10% of the variation in traffic levels. Similarly, delay at locks 18 to 27 (L18_L27) accounts for about 10% of the variation in traffic levels.

The variation in Minnesota barge rates is influenced more by delay at locks 18 to 27 than Iowa barge rates. Generally, central Iowa is open about one additional month per year than is Minnesota or that portion of Minnesota that loads most grain barges on the River. Possibly the first empty grain barge moving northward in the spring will be destined to the Iowa portion of river. Hence, some of the available barge supply is diminished for the Minnesota shipments. In which case, lock delays associated with moving empty grain barges northward to Minnesota destinations becomes increasingly critical because of the diminished supply of barges on the river. Further, the empties moving northward in the spring to transport Minnesota grain may meet southbound grain barges from Iowa that were loaded a month earlier, thus exacerbating lock delay and its affect on the Minnesota grain barge rates in the spring.

Table 2.6 presents the overall summary of forecast error variance decompositions for each variable in the one-lag Illinois River VAR model at a twelve-month horizon. In the contemporary period, 90.2% of the variation in the Illinois River grain barge rates (BRSP) is explained by itself, 3.52% by delay at the Peoria and LaGrange locks (PEO_LA), 3.66% by delay at the Melvin Price lock and lock 27 (LMP_L27), and 2.61% by number of barges transiting the LaGrange lock (TOTBGLA). After twelve months, shocks in delay on all three segments (PEO_LA, TOB_SR, LMP_L27) account for about 10% (3.61+0.43+5.54 = 9.58) of the variation in barge rates, while own barge rates still dominate the explanation of variations in barge rates (88.53%).

Variation in delay on each segment of the Illinois River (PEO_LA, TOB_SR) as well as at the Melvin Price lock and lock 27 (LMP_L27) is primarily explained by shocks in itself (Table 2.6). Traffic level on the Illinois River (TOTBGLA) is also exogenous in contemporaneous time (100%) and largely affected by itself in extended time periods (>94%).

## Concluding Remarks

The Upper Mississippi River and Illinois Waterway is the primary transportation artery for moving grain, fertilizer, and other raw materials. Particularly important is the barge transportation of grain from the north-central U.S. to lower Mississippi River ports. Since the current 600-foot lock chambers cannot allow a fifteen-barge tow and towboat to pass in one lock operation, the break-up and reassembly of the tow generates an extended processing time, which adds to congestion in the Upper Mississippi and Illinois Rivers. This study attempts to determine if lock delay affects grain barge rates that link selected sections of the UMR-IWW to the lower Mississippi River ports. Multivariate time-series analysis and directed graph methods are used to identify the causality between lock delay and grain barge rates, and to measure the impact of lock delay on grain barge rates.

One-lag Vector Autoregression (VAR) model, including information on grain barge rates, lock delays, seasonal factors and traffic levels, was formulated for both the Upper Mississippi and Illinois Rivers. F-tests (and t-tests) indicate grain barge rates on both rivers are not affected by lagged lock delays. The directed graph analysis on residuals from the VAR model representing the Upper Mississippi River shows in contemporaneous time that traffic levels on the river cause accumulated delay at locks 9 to 17 and at locks 18 to 27. Moreover, accumulated lock delay at the most congested portion of the Upper Mississippi, locks 18 through 27, was found to directly affect barge rates of Minnesota and ultimately influence Iowa barge rates. This finding suggests that Minnesota barge rates play a critical role in grain barge rate discovery. Grain shippers in the geographic periphery of the river (Minnesota) appear to bid up barge rates in order to attract barges to this portion of the river, which in turn affects grain barge rates in the Iowa portion of the river. Thus, grain barge rates appear to be discovered in the Minnesota portion of the River. For the Illinois River, the directed graph generated from the residuals of the VAR model indicates that traffic levels on the Illinois River, accumulated lock delay at the Melvin Price lock and lock 27, and the Peoria and LaGrange locks affect the Illinois River grain barge rates (south of Peoria).

Impulse response analysis shows a one hour increase in accumulated lock delay at locks 18 through 27 will increase the south Minnesota and north Iowa rates to lower Mississippi River ports by 2.83¢ and 2.14¢ per ton, respectively. The accumulated delay at the Peoria and LaGrange locks, and the Melvin Price lock and lock 27 increase the south of Peoria rate by 2.55¢ and 2.58¢ per ton, respectively. Based on the historic average delay at locks 18 through 27 (29.08 hours), the barge rate linking south Minnesota to lower Mississippi River ports is increased about $1,232 per barge as a result of this delay while the north Iowa rate is increased about $934 per barge. Further, it is estimated that delay at the Peoria and LaGrange locks, and the Melvin Price and lock 27 increase barge rates on the Illinois River about $580 per barge.

Analysis of dynamic relationships from forecast error variance decompositions suggests that innovations in delay at locks 18 through 27 on the Upper Mississippi River account for about 6.53% and 5.09% of the variation in grain barge rates of Minnesota and Iowa, respectively. For the Illinois River barge rate, innovations in delay at lock Peoria through LaGrange, and at lock Melvin Price through lock 27 together explain about 10% of the variation in barge rates.

In summary, the time-series and directed graph analyses indicate that lock delay in the lower reaches of the Upper Mississippi and Illinois Rivers increases barge rates that link the north central United States to the lower Mississippi River port area. Our findings, however, suggest that the impact on rates is not large.

# CHAPTER III

## DYNAMIC INTERACTIONS BETWEEN GRAIN MARKETS AND TRANSPORTATION RATES

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. Most export-bound grain movements are carried by maritime transportation from ports located in the lower Mississippi River (Mississippi Gulf) and the Pacific Northwest (PNW). The former essentially dominates export volume: Louisiana ports handle over 60 percent of grain exports in 2003 (USDA/AMS, 2003). The importance of the lower Mississippi River port area mainly results from the barge transportation system on the Upper Mississippi River and Illinois Waterway (UMR-IWW) that links the primary grain production area, north central United States, to the Mississippi Gulf. Historically, Louisiana ports have received about 90 percent of export grains by barge (USDA/AMS, 2003). The barge transportation on the UMR-IWW plays a critical role for the success of the north central U.S. grain production when competing in international markets.

There are several alternatives to the Mississippi 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 traveling to the Mississippi Gulf. Similarly, grain traders in Illinois may select rail rather than barge transportation on the Illinois River to deliver their grain to the Mississippi Gulf. In addition to export markets, 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, 2003, 2004). 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 modes, such as barge and rail. Accordingly, grain prices at domestic and export markets may interact with each other, as do freight transportation rates. In addition, the interaction between the transportation rates and grain prices is expected since transportation cost accounts for a significant portion of grain price in destination markets. Changes in the rate of one particular transportation mode may divert the flow and ultimately affect the grain prices at destination markets.

Several previous studies have examined the effect of transportation rates/fees (barge, rail or truck) on grain prices and flow (Babcock and German; Fellin and Fuller; Hauser, Beaulier, and Baumel). The interrelationship between grain transportation modes (barge and rail) has also been evaluated by a number of studies (Johnson; Shelton 1912c, 1914; Kelso; McCarney; Sorenson; Fedeler and Heady; Fuller, Makus, and Taylor; McDonald; Miljkovic et al.,). These studies provide considerable information and knowledge of grain transportation (barge and rail) and agricultural markets; however, none of these studies have examined the interaction of grain prices and transportation rates in a dynamic framework. Also, most of those studies generally failed to consider alternative markets and shipping routes.

Several studies have identified and confirmed the importance of transport costs in spatial market integration associated with homogenous commodities, such as Geraci and Prewo; Goodwin, Grennes and Wohlegant; McNew; and Roehner. However, few studies have focused on the role of transport costs on the grain price discovery process. Several exceptions can be found in recent literature. Haigh and Holt confirmed the effectiveness of ocean freight futures contracts on reducing the price uncertainty in the international grain marketing channel. Haigh and Bryant discovered that the volatility of barge rates contributes to the level uncertainty in grain markets. Most recently, Haigh and Bessler presented detailed discussion regarding causality and price discovery within domestic and export markets and freight rates linking these markets. Although these studies took into account transport costs and their effect 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.

In view of the importance of barge transportation in the export-bound grain marketing channel and the shortcomings of previous studies in both transportation and market integration, this paper aims to provide a broader view of the dynamic interdependence between grain and freight transportation markets. The objective of this paper is to evaluate the influence of transportation rates, especially barge rates, on the price discovery mechanism for export-bound grain, and to explore the interaction between transportation rates. The dynamics among grain prices at the export ports, selective domestic markets, barge rates on the UMR-IWW, and other transportation rates linking the production regions to destination markets will be studied. Through this study, the knowledge of how grain markets and the transportation industry react to each other over time in the export-bound grain market system can be better understood. This knowledge can help the players in this system, such as farmers, grain companies, and freight transportation industry, to generate an efficient pricing strategy.

The remainder of the paper is structured as follows: The second section presents the scope of this study. Method of analysis in this paper, which accounts for both lags and contemporaneous relationship, will be discussed in the third section. Data and variables will be presented in the fourth section, while section five will discuss the empirical results. The discussion and conclusions will be offered in the last section.

**Scope of Study**

Since the focus of this paper is on export-bound grain, two primary port regions, the Mississippi Gulf and the PNW, are included. 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 three north-central states are the primary corn and soybean production and processing regions. In addition to the demand in the north central U.S., demand in the southeast U.S., a concentrated feeding area, is also considered in this study. The Memphis grain market is chosen as a proxy for the demand in this region due to a lack of a continuous price series in eastern Tennessee or Alabama.

Transportation that links the north-central U.S. to Mississippi Gulf ports is included, in particular, barge transportation on the UMR-IWW and railroad rates linking

Illinois to the Mississippi Gulf are featured. These are critical arteries for transporting grain from the hinterland to the Louisiana port area. The principal alternative route to the export market are the railroads linking Minnesota to the PNW, which is a vital channel for shipping Minnesota grain to Pacific northwest ports. Railroads linking Illinois to Memphis are included to link production regions and domestic markets. Ocean transportation is the primary means of connecting the U.S. grain to the world market. Shipping rates linking the PNW and Mississippi Gulf to Japan are added in this analysis since Asia is the major consumer of U.S. grain products. Figure 1 offers the geographic relationship of these markets and shipping routes. These selected markets (except for Memphis market), shipping routes, and transportation modes, represent the typical channel for export-destined grain moving to Asian markets.

**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 domestic markets (Minnesota, Iowa, Illinois, and Memphis) and export port areas (Mississippi Gulf and PNW), quantities of export-destined grain exiting through these two port areas, and six freight rates including barge, railroad, and ocean transportation discussed in the previous sections. Additionally, directed acyclic graphs are employed to determine the contemporaneous relationships among these markets.

Generally, the dynamic econometrics tools used to evaluate stationary data are vector autoregression (VAR), while the appropriate technique for non-stationary and cointegrated data is the error correction model (ECM), developed by Johansen

(Johansen, 1988, 1991; Johansen and Juselius, 1990). However, previous studies have shown that cointegrated data in a levels VAR perform as well as in ECM for out-of-sample forecasting (Bessler and Fuller, 1993; Lin and Tsay). Furthermore, the levels VAR is asymptotically equivalent to the ECM for large samples (Engle and Granger). In this paper, both methodologies will be applied to the data and a test will be conducted to compare the equivalence of the results.

A VAR model with *p* lags of M variables is written:

$$(3.1) \quad Y_t = \sum_{i=1}^{p} \Gamma_i Y_{t-i} + \mu + e_t \, (t = 1,...,T)$$

where *Y* is a (Mx1) vector of series at time t, $\Gamma_i$ a (MxM) matrix of coefficients relating series changes at lagged *i* period to current changes in series, $\mu$ is a (Mx1) vector of constant, and $\varepsilon_t$ is a (Mx1) vector of innovations. Equation (3.1) indicates that each of the M variables is a function of *p* lags of all M variables, including itself, a constant and a present innovation (error) term. Similarly, an ECM model is written as follows:

$$(3.2) \quad \Delta P_t = \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \Pi P_{t-1} + \mu + e_t \, (t = 1,...,T)$$

Clearly, equation (3.2) is just a VAR model in first differences plus a lagged-level term. The ($P_{t-1}$) 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 among those series can be identified through the parameters in equation (3.2). 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 $\alpha$ and $\beta$ are (*M* x *r*) matrices. The $\beta$ matrix contains the cointegrating parameters and the matrix $\alpha$ includes the information on the speed of adjustment. Testing hypotheses on $\beta$ can provide information on long-run structure, while testing hypotheses on $\alpha$ and $\Gamma_i$ can identify the short-run relationships (Johansen and Juselius, 1994; Juselius; Johansen, 1995). Furthermore, the contemporaneous structure can be summarized through structural analysis of $e_t$, or though the directed graph analysis of the correlation matrix of the residuals from the ECM (Bessler and Lee; Bessler and Yang).

It is recognized that individual coefficients of the standard VAR and ECM models are hard to interpret (Sims). Under such cases, innovation accounting may be the best description of the dynamic structure (Sims; Lutkepohl and Reimers; Swanson and Granger). The author estimates the parameters of equation (3.1) using ordinary least squares regression and then inverts the estimated VAR to a moving average representation (MAR). The innovation accounting based on the MAR is then conducted to summarize the dynamic interactions among evaluated series. Also, the parameters of equation (3.2) are estimated using the maximum likelihood procedure of Johansen (1992). The error correction model is then converted as a levels VAR through algebraic manipulation of the estimated coefficients, and the dynamic interactions among the grain prices and transportation rates are summarized following the same procedure of innovation accounting as the VAR model.

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 VAR and ECM (Spirtes, Glymour, and 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 $\Sigma_t$ is causally sufficient. A Bernanke ordering may be used with the structure found with the directed graphs on contemporaneous structure (Bernanke; Doan).

***Directed Acyclic Graphs***

The directed acyclic graphs (DAGs) methodology employed here emanates from the field of artificial intelligence and computer science (Pearl, 2000). Economic scientists utilized this analytical engine to facilitate the inference of causal relations from observational data (Swanson, 2002; Lauritzen and Richardson, 2002). 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:

$$(3.3) \qquad P(y_1, y_2, y_3, \ldots, y_m) = \prod_{i=1}^{m} P(y_i \mid v_i)$$

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, …, 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 $A \rightarrow B \rightarrow C$; b) condition a common cause in a causal forks, say variable Z in the graph $X \leftarrow Z \rightarrow Y$; 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).

An idea upon which our analysis is based is that causal chains (A→ B→C), causal forks (A←B→C), and causal inverted forks (A→B←C) 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.

Sprites, Glymour and Scheines developed PC algorithm to infer causal relations from observational data. PC algorithm utilizes a step-wise procedure beginning with a general unrestricted set of relationships among variables. It begins with a complete undirected graph – where every variable is connected to every other variable, without directions (arrows). Connections or edges (lines) between variables are removed based on zero correlations or conditional correlations. That is, if a correlation or conditional correlation between two variables is not significantly different from zero, the edge (line) between them is removed. After considering all edges and all possible sets of conditioning variables (other variables) the final set of edges (those not removed) are directed. The notion of a "sepset" is used to carry-out this directional step. *The conditioning variable(s) on removed lines between two variables is called the sepset of the variables whose edge has been removed (for vanishing zero-order conditioning information the sepset is the empty set).* Suppose we have three variables A, B and C: directed edges between triples A – B – C appear as A → B ← C if B is not in the sepset of A and C. Further, if A → B, B and C are adjacent, A and C are not adjacent, and there is no arrowhead at B, then B – C is oriented as B → C. If there is a directed path from A to B and an edge between A and B, then orient A – B as A → B.

Fisher's $z$ (Spirtes, Glymour and Scheines, p. 94) is used to test whether conditional correlations are significantly different from zero, where

$$(3.4) \quad Z[\rho(I, J|K)N] = \tfrac{1}{2}(N - |K| - 3)^{1/2} \times LN[|1+ \rho(I, J|K)| \times (|1 - \rho(I, J|K)^{-1}]$$

and, $n$ is the number of observations, $\rho(i, j|k)$ is the population correlation between series $i$ and $j$ conditional on series $k$, and $|k|$ is the number of variables in $k$ (that we condition on). If $i$, $j$ and $k$ are normally distributed and $r(i, j|k)$ is the sample conditional correlation of $i$ and $j$ given $k$, then the distribution of $z[\rho(i, j|k)n] - z[r(i, j|k)n]$ is standard normal. The software TETRAD is developed to process the PC algorithm and its extensions (Scheines et al.).

**Data and Variables**

This section offers a brief discussion of selected variables used to measure the dynamic interdependence between grain prices, transportation rates, and grain exports in this study. Corn transportation demands are greatest of all U.S. grains due to its large volume of production. It was impossible to include several grains in analysis because of degree of freedom problems, thus the analysis focused only on the corn. Two soybean markets (one domestic, one export), however, are added in this study since both corn and soybean are largely produced in similar regions, hence they may compete for storage and transportation capacity. Further, corn and soybeans compete for acreage in many production regions; therefore, in the long-run there may be some interactions between these two commodities. The prices and quantities are aggregated monthly averages that extend from 1990 through 2002, thus a total of 156 observations. All grain prices, transportation rates, and export grain volumes were obtained from the U.S. Department of Agriculture, Agricultural Marketing Service. The descriptive statistics and plots for these variables are presented in Table 3.1 and Figures 3.2 to 3.3.

Spot export corn prices at PNW (PNW) and the Mississippi Gulf (GF) were collected as were four interior corn bid prices in Minneapolis, MN (MN), southeast Iowa (SEI), south central Illinois (CIL) and Memphis (MEM) (Table 3.1). The Minneapolis corn price (MN) is an interior price that may represent the demand in local markets, while it also may reflect the competition between PNW and the Mississippi Gulf ports.

The remaining three interior prices represent domestic grain demands. 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). Of the five corn prices included in the analyses, the highest price was in the PNW port area and the lowest was in Minneapolis (Table 3.1). The low corn price in Minneapolis is partially due its remoteness and the substantial transport costs that link the region to destination markets. The six corn prices have similar coefficients of variation (C.V.), indicating the similar volatility for all corn prices. The plot of corn prices at the six markets also suggests this relationship (Figure 3.2). Soybean prices at the Mississippi Gulf ports (SGF) and central Illinois processors (SILP) were 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. As with corn markets, the export soybean market has a higher price than domestic markets and both soybean prices move in a parallel fashion (Table 3.1 and Figure 3.2).

The barge rate (BR) used in this study is the barge rate of south Peoria (Peoria to Beardstown, IL). This spot grain barge rate reflects the current rate as a percent of the historic benchmark tariff rate (Southbound Barge Freight Call Session Basis Trading Benchmark in 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 the winter, the rates are not available in the frozen period. The Illinois River is navigable year-round and the grain barge rates on the Upper Mississippi and Illinois River are highly correlated (0.998) during those months when barges operate on both rivers. Therefore, the barge rate of south Peoria is employed in this study. The mean barge rate (BR) is about $8 per ton and seasonality is clearly observed (Table 3.1 and Figure 3.3).

Monthly average rail rates linking Illinois to the Mississippi Gulf (RIG), Minnesota to PNW ports (RMP), and Illinois to Memphis (RIM) are generated from the annual Carload Waybill Sample (Table 3.1 and Figure 3.3). Clearly, the rail rates are higher at increased distance. The rate to the PNW (RMP) is more than double the rate to Mississippi Gulf port (RIG) and four times greater than the Illinois-Memphis rate (RIM). In addition, the rail rate to Gulf (RIG) is considered as competitive to the barge rates linking north central U.S. to the Mississippi Gulf (BR). Here, the average monthly barge rate (BR) is lower than the rail rates (RIG) while the variation in BR is higher than RIG (Table 3.1).

The trend for the two ocean shipping rates, Gulf to Japan (OGJ) and PNW to Japan (OPJ), is basically comparably (Figure 3.3). The OGJ is about $10/ton higher than OPJ on average (Table 3.1). The quantities of grain exported at the Mississippi Gulf (EQG) is significantly larger than the volume transiting through the PNW (EQP), while the variation in EQP is much higher than EQG (Table 3.1 and Figure 3.3). One may notice that there are no truck rates included in this study; that is because the historical data on truck rates is not publicly available. Also, due to the long distance from the north central U.S. to ocean ports and increasing motor carrier costs with distance, truck is barely a transportation option for most grain companies to ship their product to export ports. Truck is, however, normally used for intrastate or regional shipment because of its cost advantage.

Since the study period extends thirteen years (1990:1-2002:12), several dummy variables were generated to capture the potential influence of policies and structural changes in the industry. Farm legislation probably affects grain markets and transportation. The first farm legislation was initiated in the 1920s and is now renewed about every six years. During the study period, the farm legislation was renewed and implemented in 1990:4, 1996:4, and 2002:5. Two farm legislation dummy variables were generated, 1996:4-2002:4 and 2002:5-2002:12, in this analysis. The author did not create a dummy from 1990:4 to 1996:3 since there were only three months prior to the 1990 farm legislation in our study range. Therefore, the time period before the 1996 farm legislation was aggregated into one period.

In addition to the potential role of farm legislation on agriculture, there are also noteworthy happenings in the rail industry. 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) completed a trade to form BNSF Corporation, 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) took control of Illinois Central Corporation, a railroad operating trackage that links central Illinois to the Mississippi Gulf. Rail companies involved with those three mergers all 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 those mergers was considered. Besides the farm legislation and railroad merger dummies, eleven monthly dummies were included to incorporate seasonality.

**Empirical Results**

Results of the analyses are presented in three subsections. Each subsection corresponds to a different modeling effort. The first subsection focuses on two corn prices and the barge transportation rate. The second model retains variables in the first model but adds additional domestic and port prices, and rail and ocean transportation rates. Finally, in the third model, soybean prices are included with the other analyzed prices and rates. VAR analysis is applied to the first and second models to generate initial ideas on the interdependence between these evaluated grain prices, transport rates, and exports. In the third section, both VAR and ECM analyses are applied. A test to identify difference between the two outputs is conducted and detailed discussions regarding the market interdependence will be offered. For the VAR analysis in each section, the optimal lag length is determined initially in a vector autoregressive representation of the model. Analysis of the contemporaneous innovation structure will then be implemented, followed by a summary of the dynamic interdependence among these data through the innovation accounting techniques. For the ECM model, the procedure is similar except the cointegration analysis and associated tests will be conducted prior to identifying the contemporaneous innovation structure.

***Single-Commodity, Two-Market, Barge-Transportation Model***

In this section, a simplified model with two corn prices and one transportation rate is presented to investigate the interdependence of markets and the influence of transportation costs on grain prices. Illinois and the Mississippi Gulf spot corn prices and barge rates linking these two regions are selected. Table 3.2 presents Schwarz Loss, Akaike AIC, and Hannan and Quinn Φ measures on alternative lag lengths from unrestricted vector autoregressions (VAR) to fit to these three series (in levels). The measures are fit with eleven monthly indicator variables and two dummy variables associated with farm legislation in each VAR equation to account for deterministic seasonality as well as the policy effect. Our search is over lags of zero through six periods. Interestingly, three loss function measures indicate different optimal lag length: Schwarz loss indicates a one-lag VAR, Akaiki prefers a three-lag VAR, while Hannan and Quinn suggest a two-lag VAR is appropriate. The three lag VAR by Akaiki is selected since the author believes that the consequences of under-fitting will be more costly than over-fitting.

To determine the structure of the contemporaneous relationships, the variance-covariance or correlation matrix on the innovations generated from each equation in the three-lag VAR is required. Table 3.3 contains the lower triangular correlation matrix. Barge rates (BR) are positively correlated with the corn prices at the Gulf (GF), and negatively correlated with south-central Illinois (CIL) corn prices. Both corn prices are strongly positively correlated. The correlation matrix offers a general idea of the association among these three series. For further information of the causality among these variables, PC algorithm and directed graphs analysis are employed. In Figure 3.4, the south central Illinois corn prices (CIL) are determined by the barge rates (BR) and the Gulf corn prices (GF) at the 10 percent significance level, which agrees with the findings by Haigh and Bessler (p. 1113). It shows that Illinois (CIL) is a “sink” receiving information from the barge market and the Gulf market. The information flow between the Gulf market and barge market is open when conditioning on the Illinois market.

Using the causality presented in Figure 3.4 along with the three-lag VAR model, the dynamic interdependence among the corn market in Illinois (CIL), the Mississippi Gulf (GF) and the barge rates (BR) is summarized in Figure 3.5 and Table 3.4. Figure 3.4 is the impulse responses based on the results in DAG (Figure 3.4). It depicts the dynamic response of each price/rate to a one-time-only shock in each series. Each response is divided by the standard deviation of the innovation in each series, which allows us to compare responses across markets. The response of each market to a shock (innovation) in the Gulf market (GF) is shown in the left-hand panel (Figure 3.5). The Illinois market (CIL) responds positively to a shock in GF, while the barge rates (BR) respond negatively. A positive shock in the Illinois corn price (CIL) will increase the Gulf price (GF) for several periods before declining (upper graph of the middle panel). The decrease in barge rates (BR) result from a positive shock in CIL, which is as expected since the stronger local demand will divert the grain flow from the export to domestic market. The response of corn prices to a shock in barge rates (BR) is presented at the right-hand side panel. It shows the Gulf prices (GF) will be unchanged in the first month then increase in subsequent periods. The hinterland price (CIL) initially decreases initially then increases after the second month. The response pattern indicates that increasing transport costs will increase the destination grain market price and decrease the origin market price, hence agreement with basic transportation economics. The Haigh and Bessler study use daily data and allow dynamic adjustment up to fourteen days, whereas in this study monthly data was used. When comparing the impulse function at horizon 0 in this study with the impulse function at 14-days ahead in Haigh and Bessler's study (p. 1117), the author finds the results are generally comparable.

Table 3.4 presents the decompositions of the forecast errors for each series at alternative horizons. In this case, the forecast horizon is up to twelve months. The first column labeled "Std. Error" is the standard error of the forecast for each particular series. The numbers in remaining columns partition the uncertainty in each class at various horizons. The sum of each row should be 100%, or close to 100% due to rounding. For the export corn price at the Gulf (GF) in the top panel, the Gulf market (GF) is 100% exogenous in contemporaneous time (Horizon 0), which agrees with the DAG analysis: the GF is not affected by either barge rates (BR) or Illinois corn prices (CIL) (Figure 3.4). At one period (one month) ahead, the uncertainty of GF is still strongly influenced by itself [98.23%]. However, the influence of barge rates (BR) becomes stronger at extended time periods. At six month ahead, about 20% of the variation of the GF is explained by BR and about 78% by itself. At one year, the influence of BR increased to 42.24% although the influence by GF itself is still greater than 50% [56.66%]. The Illinois corn price (CIL) has very little influence (less than 2%) on the GF over all time periods.

Illinois corn prices, in the second panel (CIL), are primarily influenced by the Mississippi Gulf corn prices (GF). About 86.65% of the variation in CIL is explained by GF, 8.78% by itself, and 4.57% by barge rates (BR) in the short run (Horizon 0). This is consistent with the findings in the DAG that indicate the GF and BR 'cause' the CIL in contemporaneous time (Figure 3.4). At one month ahead, the influence of GF on CIL is even higher [91.29%] while the influence by itself and BR is weaker. However, in the long run (twelve month ahead), the influence of GF on the variation in CIL is decreasing (but still about 60%) while the influence of BR increases to almost 39%.

In the third panel, which features the barge market (BR), the variation of BR is solely explained by itself in the short run [100%], which parallels the causality results in DAG. Over all time periods (one month, six month, and twelve month ahead), the BR is heavily explained by itself (more than 88%). The Gulf market (GF) explains about 9% of the variation in BR in the long run.

From the presentation above, one may question if barge rates (BR) have such an important influence on export and domestic corn prices (GF, CIL), and if the barge market is exogenous in the export grain market channel. It is thought that the findings here may result from the simplified model structure. The three-variable model examined here demonstrates the interdependence of various happening in an export grain market channel. The influence of barge rates on corn prices may represent transaction forces but not barge itself. Similarly, the variation in barge rates may be explained by other competing or cooperating transportation modes, which are not included in this model. To evaluate this hypothesis and explore more detailed interaction within the grain distribution system, a multi-market, multimode-transportation model will be examined.

***Single-Commodity, Multi-Market, Multimode-Transportation Model***

In this section, the previous simplified model is expanded to a multi-market, multimode-transportation model. In addition to the Mississippi Gulf (GF) and south central Illinois (CIL) corn prices, this section includes one more export price, Pacific Northwest (PNW), and three more domestic markets, Minneapolis (MN), southeast Iowa (SEI) and Memphis (MEM). For transportation options, together with barge rates (BR), railroad and ocean transportation costs are added. Rail rates linking Illinois to the Mississippi Gulf (RIG), Minnesota to PNW ports (RMP), and Illinois to Memphis (RIM) are included while ocean shipping rates linking the Gulf to Japan (OGJ) and linking the PNW to Japan (OPJ) are included. Also, corn exports at the Mississippi Gulf (EQG) and the PNW (EQP) are incorporated in this system. There are a total of fourteen series that are evaluated. Moreover, besides the seasonal and the farm legislation dummy variables, three mergers in the railroad industry (as discussed in Data Section) are included in this model.

The optimal length of lags for the VAR model is initially determined. In Table 3.5, Schwarz loss, and Hannan and Quinn Φ indicate a one-lag VAR is appropriate while Akaike AIC information prefers a two-lag VAR. Based on the same reason discussed in the first section (under-fitting vs. over-fitting), the two-lag VAR by Akaiki is selected. The correlation matrix resulting from the innovations from each equation in this two-lag

VAR is used to identify the contemporaneous causality structure. The lower triangular correlation matrix is presented in Table 3.6, which shows a strong correlation among all corn prices (PNW, GF, MN, SEI, CIL, and MEM). Barge rates (BR) are positively correlated with the two export corn prices (PNW, GF) and negatively correlated with corn prices at domestic markets. The correlation between the three rail rates (RIG, RMP, RIM) and corn prices is generally modest (<=0.06). Interestingly, ocean freight rates (OGJ, OPJ) present stronger correlation (absolute value is about 0.2) with several domestic grain market prices (MN, SEI, CIL, MEM) than the two export prices. The other interesting finding is in regard to corn exports: the correlation between corn exports at PNW (EQP) and corn prices is relatively strong as compared to that between corn exports at the Gulf (EQG) and corn prices, although EQG is definitely higher than EQP (Table 3.1).

Using the correlation matrix presented in Table 3.6, the contemporaneous causal relationships among the fourteen series are generated by DAG at the 10 percent significance level (Figure 3.6). Here, the southeast Iowa prices (SEI), barge rates (BR), and rail rates linking Illinois and Memphis (RIM) are exogenous in the short run. The SEI passes information to other domestic markets (Illinois (CIL), Memphis (MEM), and Minneapolis (MN)), then affects the export market at the Gulf (GF) and ultimately ‘causes’ the prices at PNW (PNW). It shows the domestic demand shifts the export markets. Although it contradicts the findings in the simplified model in the previous section (Figure 3.4), it is quite reasonable since the domestic demand accounts for 80 percent of the total U.S. corn consumption. In other words, the domestic markets may possess a stronger influence on price. Barge rates (BR) are the information starter which affects the export quantities at the Gulf (EQG) and PNW (EQP), rail rates linking Illinois and Gulf (RIG), and, interestingly, the ocean freight rates from PNW to Japan (OPJ). Ocean freight rates linking the Gulf and Japan (OGJ) 'cause' the ocean rates linking PNW and Japan (OPJ), which is consistent with the study by Haigh, Nomikos, and Bessler (p.155). In this system, corn prices at the PNW (PNW), corn exports at PNW (EQP), ocean rates linking PNW and Japan (OPJ), and rail rates linking Illinois and the Gulf (RIG) are the information "sinks".

Based on the two-lag VAR model results together with the causal relationship in Figure 3.6, the author summarizes the dynamic interdependence among corn prices, transportation rates and export volume in a presentation of impulse functions (Figure 3.7) and forecast error variance decompositions output (Table 3.7). Similar to the previous section, the dynamic response of each series to a one-time-only shock in each variable is presented in the impulse response function output. This graph consists of all responses of each variable to all other variables and it provides a sense of the overall pattern of responses. It can be seen that the south-east Iowa corn prices (SEI) have the most significant influence on other corn prices. Barge rates (BR) also influence all corn prices and ocean freight rates (OGJ, OPJ). In addition, ocean freight rates linking the Gulf and Japan (OGJ) have considerable impact on all corn prices.

Table 3.7 presents the forecast error variance decompositions of each series based on DAG results. The maximum forecast horizon is twelve months. Recall from the previous section, the numbers in each column partition the uncertainty in each class at alternative horizons. Table 3.7 contains plentiful information including: a) interdependence within corn markets; b) interrelationship between corn markets and transportations modes; and c) interaction between the transportation markets. For export corn prices in the PNW (PNW), the uncertainty associated with current prices is primarily explained by current period shocks in southeast Iowa price (SEI) [63.65%] and its own price [28.06%]. Gulf price (GF) explains about 5% of the variation in the PNW. At one month ahead, the uncertainty in PNW is still primarily influenced by the SEI [64.68%] and itself [17.59%]. At the long horizon of one year ahead, SEI is still the most influential corn market to PNW, however, the influence has decreased to about 26%. Similar partitions can be found for all other corn prices (GF, MN, SEI, CIL, and MEM). The evidence presented in Table 3.7 indicates, in this system, Iowa corn price primarily explains the variation in other corn prices, which is basically parallel with the DAG results in Figure 3.6.

Interrelationships between corn markets and transportation rates are interesting to explore. Barge rates (BR) explain about 15-17% of the variation in all corn prices at one year ahead (Horizon 12), which is significantly lower than the findings in the simplified model (Table 3.4). Rail rates linking Minnesota to PNW (RMP), the most influential rail rate, explain 6-9% of the variation in corn prices. The three evaluated rail rates explain together 7-9% of corn price variation in the long run. Surprisingly, ocean rates linking the Gulf and Japan (OGJ) present very strong explanatory power [17-25%] in the variation of all corn prices, which indicates the considerable volatility in international freight rates has an impact on grain prices.

In view of the interdependence among transportation modes, in the long run, about 6.65% of the variation in BR is explained by three rail rates together, while the RMP is the primary influence [6.03%]. Reciprocally, shocks in BR explains about 9%, 7% and 2% of the variation in rail rates linking Illinois and the Gulf (RIG), Minnesota and PNW (RMP) and Illinois and Memphis (RIM), respectively. In addition, about 12% of the variation in barge rates (BR) is explained by ocean rates linking the Gulf and Japan (OGJ). In contrast, BR explains about 13.5% of the variation in ocean rates linking the Gulf and Japan (OGJ) and 16.7% of ocean rates linking PNW and Japan (OPJ). Consistent with the results in DAG, OGJ dominate the freight markets, explaining almost 56% of the variation in OPJ. Interestingly, interdependence between some rail rates and ocean shipping rates are found. In the long run about 11% of the variation in RIG is explained by ocean shipping rates linking the Gulf and Japan (OGJ). Interestingly, about 16.6% of the variation in the rail rates linking Minnesota and the PNW (RMP) are explained by OGJ.

Between export quantities and corn prices, corn exports at the Gulf (EQG) and PNW (EQP) together explain about 5-8% of the variation in corn prices. Corn prices together explain about 19% and 10% of the variation in EQG and EQP, respectively. Corn export volume at both ports does not have a significant impact on transportation rates. However, variation in corn exports at PNW (EQP) is explained by barge rates (BR) about 22% and by ocean rates that link the Gulf to Japan (OGJ) about 28%.

There is one thing noticeable in the output of the forecast error variance decompositions. The six transportation rates together explain approximate 42-50% of the variation in corn prices, which is primarily contributed by the ocean shipping rates linking the Gulf and Japan (OGJ) [17-25%], and the barge rates on the UMR-IWW (BR) [15-17%]. It is very important to understand and interpret the percentage correctly. The number here is the percent of the variation in the *forecast error*, not the actual price. Explicitly, shocks in ocean rates of Gulf to Japan and barge rates on the River affect the stability of corn prices considerably. In fact, previous studies showed the contribution of hedging ocean freight rates in reducing the price uncertainty of grain, and identified the impact of volatility of barge rates on uncertainty in market levels (Haigh and Holt; Haigh and Bryant). Results obtained in this study basically correspond to their findings.

In this section, a multi-market, multimode-transportation corn model is developed and evaluated. Generally speaking, the southeast Iowa market has the most influence over other corn markets. The dynamic impact of transportation rates on corn prices was explored. In particular, barge rates explained less than 20% of the variation in corn prices. Also, the interrelationship among transportation modes in the U.S. grain export market was considerable.

***Multi-Commodity, Multi-Market, Multimode-Transportation Model***

In contrast from the previous two models, the evaluated model here consists of two grains: corn and soybeans. In addition to the original corn prices and transportation rates, the author now includes soybean prices in the analyses. Due to the limitation of the sample size, only one domestic market, Illinois processor (SILP), and one export soybean market, the Mississippi Gulf (SGF), are added. The author also integrates the soybean and corn export volume as the total grain export quantities in this section.

Following the form in the previous section, impacts of seasonality, farm legislation and rail mergers are also taken into account.

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 Dickey-Fuller and Augmented Dickey-Fuller tests are presented in Table 3.8. The null hypothesis of these two tests is that each evaluated series is mean non-stationary. Dickey-Fuller tests show that all grain prices (corn and soybeans) are non-stationary since the t-statistics are all greater than the critical value of -2.89. Moreover, all transportation rates, except for two ocean rates (OGJ, OPJ) are mean stationary. Two grain export series are also mean stationary. However, the Augmented Dickey-Fuller tests offer different perspectives regarding the stationarity of corn prices: Minneapolis (MN), southeast Iowa (SEI), and south central Illinois (CIL) corn prices are found to be mean stationary. Since residuals from Augmented tests statistically outperform that from Dickey-Fuller test (the p-value of Q-statistic is generally higher under Augmented tests), the author adopted the results of the Augmented tests. Hence, there are nine stationary and seven non-stationary series. Under such circumstances, both error correction model (ECM) and vector autoregression model (VAR) are employed and a test will be carried out to compare the covariance matrix generated from the innovations from the ECM and VAR models.

As in the previous two sections, the optimal lag length must be determined prior to further analysis. Based on the Akaike measure in Table 3.9, a two-lag ECM model is formulated using the maximum likelihood method (Johansen and Juselius, 1990). Since there are six corn prices, two soybean prices, two export quantities, and six related transportation rates incorporated into one system, one can expect cointegration. Table 10 presents a series of trace tests on the degree of integration, the number of cointegrating vectors in this sixteen series space. Tests for both a constant in the conintegrating vectors (headed as $T^*$) and a constant outside the cointegrating vectors (headed as $T$) are included. Following the sequential testing procedure suggested by Johansen (1992), twelve cointegrating vectors with the constant (indicated in Table 3.10 by the "$_+$") are included in the cointegrating space.

Given twelve long-run stationary relations are present in the sixteen series, it is possible that one or more of the markets are not involved with any of the twelve vectors. Table 3.11 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 with twelve degrees of freedom (as imposing a zero associated with market *i* in each of the twelve vectors). The null hypothesis for all prices, rates and volume is rejected in Table 3.11 since the chi-squared statistic for each of them is greater than the 5% critical value (21.03). Therefore, all sixteen series are in the cointegration space.

Although each series is in the cointegration space, it is possible for some series not to 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 3.12, 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 one transportation rate (OGJ), most series appears to change to restore the long-run equilibrium when new information distracts.

As discussed earlier, the individual coefficient estimates from the ECM model are difficult to interpret. Similar to the VAR, the innovation generated from the ECM is used to study the contemporaneous causal relations. Table 3.13 gives the contemporaneous covariance between innovations in each of the sixteen series from the ECM. To make a comparison regarding the contemporaneous structure between ECM and VAR, a two-lag VAR is estimated and its contemporaneous covariance matrix is offered in Table 3.14. The elements of the two covariances look comparable; therefore, a test for homogeneity of covariances is conducted. A likelihood ratio (LR) test is applied to the two covariances under the null hypothesis that the two covariances are equivalent (Mardia, Kent, and Bibby, p. 140). The maximum likelihood estimator of each covariance under the null hypothesis is a weighted average covariance. This LR test has an asymptotic chi-aquared distribution with $(1/2)p(p+1)(k-1)$ degrees of freedom where $p$ is the number of series and $k$ is the number of covariances. In this case, the $p$ equals sixteen and $k$ is two. The LR test statistic for this model is 7.987 and is asymptotically distributed as $\chi^2_{136}$. This was found to be insignificant at the 5 percent level, indicating the covariance of the innovations generated from the two-lag VAR and ECM models are statistically invariant. In other words, the contemporaneous structure is identical between the VAR and ECM models. Since those two covariance matrix are statistically indifferent, the author decides to use the maximum likelihood estimator of the two covariances, the weighted average covariance matrix (presented in Table 3.15), to determine the causal relationship among the sixteen series.

Figure 3.8 is the directed acyclic graphs derived from the weighted average covariance between innovations in each of the sixteen series. Using PC algorithm at the 15 percent level, the causality among, corn prices, soybean prices, transportation rates and grain exports are generated. In Figure 3.8, Minneapolis corn price (MN) and grain export at PNW (EQP) are exogenous in contemporaneous time. Directed arrows originate from these two variables and no directed arrows into them are observed. For corn markets, Minneapolis price (MN) starts the price information flow passing the influence to other markets while the PNW export market (PNW) and south central Illinois market (CIL) are the information "sinks" in contemporaneous time. The Memphis corn market (MEM) receives information from the southeast Iowa corn market (SEI) and forwards it to the soybean price at the Gulf (SGF), which ultimately affects the Illinois processor soybean price (SILP). Ocean freight rates linking the Gulf and Japan (OGJ) receive price information from the soybean Gulf market (SGF) and pass it to ocean rates that link the PNW to Japan (OPJ) and ultimately 'cause' the rail rates linking Illinois and Memphis (RIM) via barge rates (BR) and rail rates linking Illinois and the Gulf (RIG).

The causal relationships between these sixteen series are somewhat different from the findings in the "corn only" model in the previous section (Figure 3.6). The causality among corn markets change to some extent, for example, Minneapolis price (MN) 'causes' southeast Iowa price (SEI) in this analysis, however, the reverse direction was found in the previous model. Similar situations can also be found between transportation rates as well as export grain quantities. Basically, it is not easy to clarify which specific price is the source of the information flow or to identify an absolute causality pattern in a highly integrated and information-sensitive market channel, especially exploring aggregated monthly data over twelve years. At some points of time, one price may lead, while the other price may initiate changes in different time periods. However, there are still some common findings between Figures 3.6 and 3.8. Generally, the price information flow starts from domestic corn markets, particularly in the north central U.S. This is reasonable as the north central U.S. is the primary corn production region, also an intense corn processing area. Further, the price information is rapidly extend or diffused among the other prices, rates and quantities in the grain market channel. Once price at one market changes, the other markets respond quickly and the information passes through the whole pricing system in contemporaneous time.

Based on the identified contemporaneous causal structure, impulse response functions, the response of each series to a one-time-only shock on every other price, for the estimated ECM and VAR model are presented in Figures 3.9 and 3.10, respectively. Similar to Figure 3.7, the purpose of these figures is to provide a basic idea of all responses by viewing the overall pattern in one graph. The ECM model output (Figure 3.9) shows the Minneapolis corn price (MN) generally dominates the grain prices (both corn and soybeans), while Illinois soybean processor price (SILP) has a significant influence on corn markets. Among all transportation rates, ocean rates linking the Gulf and Japan (OPJ) have the greatest impact on grain prices. A similar pattern can be found in the impulse functions of the VAR model (Figure 3.10).

Table 3.16 summarizes the forecast error variance decompositions on prices and quantities for each of the sixteen series in a two-lag ECM model. A forecast horizon up to twelve months is examined. Similar to the previous section, discussion will start with grain market interaction, followed by the impact of transport costs on grain prices, and the interrelation among transportation markets. The variation in corn price in PNW (PNW) is explained by shocks in itself [34.39%], corn price at the Gulf (GF) [17.08%], Minneapolis corn price (MN) [43.79%], and southeast Iowa corn price (SEI) [4.73%] in contemporaneous time. At a one-month horizon (Horizon 1), influence from soybean prices (SGF, SILP) and transportation rates emerge. When time moves one year ahead, shocks in the six corn prices together explain about 34.65 percent of the variation in PNW price while Minneapolis price (MN) is the most influential corn price [15.72%]. In the long run, shocks to the Illinois soybean processing plant price (SILP) account for about 10 percent of the variation in PNW price. For the Mississippi Gulf corn export price (GF), the influence from the Minneapolis corn price (MN) and Illinois soybean processing price (SILP) are even higher. At a very short time period (Horizon 0), shocks in the MN price are responsible for 67 percent of the variation in the Gulf corn price (GF). At twelve months ahead, the MN price is still important in explaining the variation of the GF price [22.59%], while Illinois soybean processing price (SCILP) is an influence on Gulf corn price [18.43%]. Four domestic corn prices, Minneapolis (MN), southeast Iowa (SEI), central Illinois (CIL), and Memphis (MEM), have similar patterns as the Gulf corn price. Of the two soybean prices, the Gulf (SGF) and the Illinois processing price (SILP), the Gulf soybean price is important in explaining the variation in the forecast error [31-35%].

Interestingly the Illinois soybean processing price (SILP) has a considerable influence on the uncertainty associated with both the domestic and export corn prices in the long run [10-25%]. It suggests the domestic soybean market affects the future corn price. In general, when soybean prices are greater than 2.4 times the price of corn, farmers will increasingly plan soybeans at the expense of corn. Hence, a positive (negative) shock in soybean price in the current period may motivate farmers to plant more (less) soybeans and less (more) corn, and this ultimately affects the corn price in the subsequent harvest season.

The dynamic impact of transport costs on grain prices can be observed in Table 16. Shocks in barge rates (BR) explain about 0-5% of the variation in six corn prices in the long run, while explaining about 7-10% of the variation in soybean prices at extended time periods. As compared to the results in the "simplified-corn" model (Table 3.4) and the "expanded-corn" model (Table 3.7), the influence of barge rates on the variation in corn prices has declined. Shocks in the Minnesota rail rates to the PNW (RMP) explain 4-7% of the variation in corn prices, while rail rates linking Illinois and Gulf (RIG) have a greater influence on soybean prices [5-7%]. The overall influence of the three rail rates (RIG, RMP, RIM) on corn and soybean prices is about 7% and 9%, respectively. Again, the volatile ocean rates have a very strong influence on the variation in domestic grain prices. Two evaluated ocean rates (OGJ, OPJ) explain about

13-23% of the variation in the six corn prices and about 13-15% variation in the two soybean prices. The feedback of grain prices on transportation rates is also exhibited here. The six corn prices together explain about 18% of the variation in BR at one year ahead, while the two soybean prices jointly explain about 22% of the variation. Also, shocks in the six corn prices collectively explain about 10-20% of the variation in the three evaluated rail rates and about 8-16% of the two ocean rates. The two soybean prices explain about 3-6% and 6-13% of the variation in rail rates and ocean rates, respectively.

The variation in barge rates (BR) is primarily explained by itself in the current period as well as twelve month ahead. In addition, shocks in the three rail rates (RIG, RMP, RIM) together account for about 4% of the variation in barge rates in the long run. In contrast, shocks in barge rates explain about 4-10% of the variation in three rail rates. Particularly, barge rates (BR) explain about 10 percent of the variation in the rail rates linking Illinois and the Gulf (RIG) in the long run, which indicates the barge rates on the UMR-IWW affect the pricing strategy of the railroad servicing the same market. Two ocean rates (OGJ, OPJ) together explain about 10 percent of the variation in BR, while the ocean rates linking the Gulf and Japan (OGJ) are the primary factors of influence [8.84%]. Conversely, shocks in BR explain about 2-5% of the variation in the two ocean rates. Interestingly, two ocean rates (OGJ, OPJ) have more influence on rail rates (RIG, RMP, RIM) than the reverse influence of rail rates on ocean rates. The two ocean rates explain about 10 percent of the variation in rail rates linking Illinois and the Gulf (RIG), 21% of the variation in rail rates linking Minnesota and PNW (RMP), and about 3% of the variation in rail rates linking Illinois to Memphis (RIM). However, the influence of the three rail rates together account for only 2-6% of the variation in ocean rates.

As expected, an interrelationship between grain prices and export grain quantities was discovered. Export grain quantities at the Gulf (EQG) and PNW (EQP) comprise about 20-23% of the variation in the two export corn prices (PNW, GF) and about 17% of the export soybean price (SGF) in the long run. About 14-20% of the variation in the domestic grain price (corn: MN, SEI, CIL, and MEM; soybeans: SILP) is explained by the two export quantities at one year ahead. Reciprocally, six corn prices and two soybean prices explain about 33% of the variation in EQG and about 9% of the variation in EQP twelve months ahead. About 4-10% of the variation in export grain quantities is explained by shocks in barge rates (BR), while the three rail rates (RIG, RMP, RIM) together explain about 4-7%, and the two ocean rates (OGJ, OPJ) jointly explain about 10-30%. In contrast, shocks in export volume at the Gulf and PNW account for less than 10% of the variation in all transportation rates.

The forecast error variance decompositions on each series from the sixteen evaluated variables in a two-lag VAR is presented in Table 3.17. Since the outputs of the VAR are parallel to the ECM results to some extent, a detailed interpretation of each series is not offered to avert redundant discussions. Generally, Minneapolis corn price (MN) dominates the corn market while soybean price at the Gulf (SGF) is important to the soybean market in the long run. Interestingly, shocks in soybean prices together explain about 7-12% of the variation in corn prices, which is lower than what are observed in the ECM [10-26%]. Shocks in the six corn prices jointly account for 19% of the variation in soybean prices: this closely parallels the ECM output [17%]. Barge rates (BR) explain about 2-5% of the variation in corn prices and about 4% of the variation in soybean prices at one year ahead. Three rail rates (RIG, RMP, RIM) together explain about 5-8% of the variation in grain prices (corn, soybeans). In addition, shocks in two ocean rates (OGJ, OPJ) explain about 29% of the variation in export corn prices (PNW, GF) and about 20-25% of the variation in domestic corn prices. About 15-18% of the variation in the two soybean prices (SGF, SILP) is explained by shocks in two ocean rates in the long run. Shocks in export quantities (EQG, EQP) account for less than 9-12% of the variation in corn prices and about 17% of the variation in soybean prices. Regarding the interaction of transportation rates, the two ocean rates have the most influence on other transportation rates, except the rail rates linking Illinois and Memphis (RIM), in the long run.

Table 3.18 summarizes the impact of transportation rates on grain prices from all four models (simplified-corn, extended-corn, corn-soybeans-in-VAR, and corn-soybeans-in-ECM). For export corn markets, barge rates account for about 42 percent of the variation in corn prices in the simplified-corn model in which barge is the only transportation mode considered in the analysis. When more grain markets and transportation options are included in the models, the influence of barge rates on corn price decreases considerably from 42% to 15% and finally to about 1%. Previous studies generally suggest that the barge rates explain less than 15 percent of the variation of grain prices, which basically agrees with the findings in the extended models here (Bessler, Fuller, and Khan; McKenzie; Yu, Bessler, and Fuller). The three rail rates together explain less than 10 percent of the variation in export corn prices in all models in the VAR and ECM analysis. The two ocean rates linking the U.S. and Japan have considerable impact on the variation of export corn prices [18-29%]. Overall, shocks in transport costs (barge, rail and ocean) account for 40-50% of the variation in export corn prices in the three models analyzed using the VAR mechanism. Even with market cointegration considered in the ECM analysis, transportation rates still explain about 25-32% of the variation in export corn prices. For domestic corn markets, the influence of barge rates on the variation in grain prices also declined from almost 39% in the simplified-corn model to about 2% in the corn-soybeans-in-ECM model. Rail rates have similar impacts on domestic markets as export markets, while ocean rates have less explanatory power on domestic corn prices as compared to export corn markets. The aggregate influence of transportation rates on domestic corn prices ranges between 29 and 48% in the VAR analysis and less than 30% using the ECM mechanism, which shows transportation rates have a greater impact on export corn markets than domestic markets. For the soybean markets in the VAR analysis, shocks in barge rates, rail rates, and ocean rates explain about 4%, 7% and 18% of the variation in the export soybean price, respectively. The overall impact of transportation rates on export soybean prices in the VAR analysis is less than 30%. A similar pattern can be found in the domestic soybean market. About 30% of the variation in the domestic and export soybean markets, in the ECM analysis, are affected by shocks in transport rates.

A consistent and obvious finding in Table 3.18 is that the transportation rates have a significant influence on the variation in grain prices in the long run, which is primarily contributed through the ocean freight rates. As discussed above, previous studies have shown that hedging volatile ocean rates can reduce uncertainty in the international grain market channel. Based on this analysis, the unanticipated increase in ocean freight rates over the past two years has had an important impact on market channel costs. Both the grain producers in the U.S. and the importers of U.S. grains are made worse off from high ocean rates.

**Concluding Remarks**

Studies evaluating the relationship between grain prices and transportation rates are primarily 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 interaction between grain prices in export and domestic markets and transportation rates linking these markets over time. The primary grain evaluated in this study is corn while soybeans are also considered in the analysis. This study covers two dominant grain export ports (the Mississippi Gulf and PNW), three primary grain production and consumption markets in the north-central U.S., and Memphis representing the southeast domestic demand. Also, included into the analyses are barge rates linking the north central U.S. to the Gulf, ocean shipping rates linking the two U.S. ports to Asia, and rail rates linking the Midwest to Memphis, the Gulf and PNW. Export grain quantities at the Gulf and PNW are also taken into account. There are a total of sixteen monthly series extending from 1990-2002.

Employing time-series analytical mechanisms and directed acyclic graphs analysis, the study has evaluated the dynamic interrelationships among grain prices, transportation rates, and export volumes in three model frameworks. Sixteen evaluated series were found to be linked together in eleven long-run cointegration relationships in the corn-soybean model. A test of exclusion indicated all of the sixteen prices and quantities are in the same cointegration space while the test of weak exogeneity suggested only ocean rates linking the Gulf and Japan do not respond to shocks (perturbations) in the long-run (cointegrating space).

The VAR analysis shows that shocks in transportation rates (barge, rail, and ocean) explain a great proportion of the variation in corn and soybean market prices in the long run [30-50%]. With market cointegration, as taken into account in the ECM techniques, transportation rates account for 20-30% of the variation in grain prices (corn, soybeans). The consistently high proportion in grain prices explained by transportation rates suggests the importance of transportation in grain price determination. The volatile ocean freight rates are the most important source contributing to the variation in grain prices. In addition, the explanatory power of barge rates on corn prices varies significantly in different models. However, based on previous studies and results in the more informative models here, shocks in barge rates likely explain less than 15 percent of the variation in grain prices. Additionally, the rail rates have consistently low impacts on grain prices (less than 10%).

The dynamic interrelationships among the six evaluated transportation rates also present interesting findings. Less than 10% of the variation in barge rates is explained by the three rail rates in the long run. Reciprocally, shocks in barge rates consistently explain less than 10 percent of the variation in rail rates. In addition, barge rates explain about 7-15% of the variation in the two evaluated ocean shipping rates in the VAR analysis. The two volatile ocean rates jointly determine 12-16% of the variation in barge rates in the long run. When the cointegration of markets is considered, the influence of barge rates on ocean freight rates decrease to 2-6%, while the feedback from ocean rates to barge rates is about 10%. Further, 12-20% of the variation in rail rates linking production regions and export ports (Illinois to the Gulf, Minnesota to PNW) is explained by the two ocean shipping rates that link the U.S. to Japan in the long-run. In contrast, shocks in three rail rates explain less than 6 percent of the variation in ocean freight rates.

In addition, perspective about price discovery in the study region corn and soybean markets is generally illustrated in this study. Results from the three models suggest that there is no explicit and permanent price leader in the corn market in the long run; however, the north central market likely have the most influence over other markets due to its heavy production and consumption. Soybean export price dominates the soybean market. Interactions between soybean and corn prices are also observed.

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

# CHAPTER IV

# ESTIMATION OF GRAIN BARGE DEMAND ON THE UPPER MISSISSIPPI RIVER AND ILLINOIS WATERWAY

The United States is the primary producer and exporter of corn, soybeans, and wheat. Most of the export-bound grain is shipped to Mexico, Asia and Europe through the lower Mississippi River ports, which handles over 60 percent of the U.S.'s annual grain outflow historically (USDA/AMS, 2003). The Upper Mississippi River and Illinois Waterway (UMR-IWW) is the primary transportation artery for moving corn, soybeans and wheat production from the north central U.S. to the lower Mississippi River ports. Historical data show about 45 million metric tons of food and farm products are annually transported to Gulf ports via the Upper Mississippi River with 90 percent comprised of corn and soybeans (USACE, 2002b).

Although the importance of the UMR-IWW to U.S. agriculture is considerable, very few studies have addressed demand for grain barge transportation on the River. Exceptions include the papers by Harnish and Dunn and Mijkovic et al. Harnish and Dunn estimated a reduced-from model to explore the determinants of grain barge rates on the Mississippi River System (including Mississippi, Illinois and Ohio Rivers) in the short run. They selected eight segments of the River system and conducted an individual and pooled estimation. Their results suggested that grain exports, coal barge rates, input prices (fuel, labor), and distance influence grain barge rates. Miljkovic et al. conducted a system econometrics estimation including both rail and barge transportation modes for export-bound grain movement. Supply and demand equations associated with the rail and barge market linking Illinois to the Gulf of Mexico were evaluated in an econometric approach. The findings suggested these two transportation modes were partial substitutes. The negative own price-quantity relationship was also found. The export grain level, however, did not have a statistically significant effect on the demand for both barge and rail modes. The dependent variable in the demand function was price (barge rate, rail rate), hence the elasticity could not be obtained. Their results suggested that the own price-quantity flexibility of barge demand ranging between –0.485 and –0.541.

There are additional studies related to grain movement on inland waterways in system beyond the Mississippi. Hauser, Beaulieu, and Baumel studied the impact of inland waterway user fees on the grain flow pattern among rail, barge and truck markets, and calculated an implied demand elasticity for barge transport. Babcock and German evaluated and forecasted the impact of the diesel fuel tax on the demand for U.S. waterway traffic. Fellin and Fuller estimated the effect of the waterway user tax on the U.S. agricultural and transportation markets. Oum formulated an intermodal network between rail, road and inland waterways in Canada. Beuthe et al. employed a detailed multimodal geographic information system (GIS) network model to assess direct and cross-elasticities for rail, road and waterway transport in Belgium. In addition, several studies focused on the forecast of barge traffic (Wilson and Sander; Tang; Babcock and Lu).

None of the previous studies yielded direct estimates of the price elasticity for grain barge demand on the Upper Mississippi River. The knowledge of grain barge demand on the River is important to the barge industry, farmers and authorities that maintain and manage the lock system on the River. Understanding grain barge demand would enable the barge industry to provide more adequate service during peak/off-peak periods so their operation costs could be reduced. Grain exporters can also benefit from the knowledge as an input to better plan their distribution strategy. Moreover, this information is a key input in the economic feasibility analysis of waterway infrastructure improvement. It is particularly critical nowadays due to the controversies regarding the expansion of the aging lock system on the Upper Mississippi River. Economic benefits from improving inland waterway transportation infrastructure are conceptually based on a demand schedule that relates barge companies willingness to pay for improved navigability of the waterway. A portion of the area under the demand relationship (consumers' surplus) would offer a measure of the gross benefits from the infrastructure improvement. For this reason, knowledge of the demand characteristics for barge transportation on the Upper Mississippi is worth exploring. The purpose of this paper is to estimate the structural demand for grain barge transportation on the Upper Mississippi River and provide useful information to interest groups.

**Theoretical Foundation**

Since the demand for grain barge transportation is a derived demand, any factors that shift supply and demand curves in production regions and demand curves in export markets will consequently move the demand for barge transportation (Boyer). Tang presents an extensive discussion on the demand for grain barge transportation. A two-region spatial equilibrium model is used to illustrate the theoretical foundation of grain barge demand (Figure 4.1). Panel A depicts the supply ($S_x$) and demand ($D_x$) of grain (e.g., corn) in the north central United States while Panel C represents the rest-of-the-world's (ROW) excess demand for grain localized at lower Mississippi River ports. Panel B, the trade panel, includes the excess grain supply of the north central region ($ES_x = S_x – D_x$) and the excess demand of the foreign regions that purchase grain at lower Mississippi River ports ($ED_m = D_m – S_m$). The intersection of excess supply ($ES_x$) and excess demand ($ED_m$) relates the equilibrium price and quantity of grain traded between the north central U.S. and lower Mississippi River ports if no transportation costs were required to link the two regions. However, transportation costs are important in the marketing of grain. The derived demand for grain transportation and the supply of grain transportation service are represented in Panel D. The derived transportation demand is equal to the vertical distance between the excess supply ($ES_x$) and excess demand ($ED_m$) in Panel B. Also shown in Panel D is the supply of transportation service linking the north central U.S. to lower Mississippi River ports. Since barges transport the majority of grain from the north central region to lower Mississippi River ports (+90 percent), it is reasonable to assume the supply is representative of the grain barge fleet operating on the Upper Mississippi River. The intersection of the derived transport demand and supply determines the transportation rate linking the north central U.S. to lower Mississippi River ports and the corresponding grain prices in the hinterland ($P_x$) and port area ($P_m$) (Panel B), where grain prices in the two regions ($P_x$ and $P_m$) differ by the barge transport rate that link the two regions. Any force shifting the regional supply ($S_x$) and demand ($D_x$) of grain in the north central U.S. will shift the excess supply of grain ($ES_x$) and the derived transportation demand. Similarly, shifts in rest-of-the-world (ROW) excess demand and supply will also alter the derived demand for transportation. Therefore, these forces need to be considered when estimating the demand for grain barge transportation.

In addition to those forces discussed in the partial equilibrium representation in Figure 4.1, other important factors such as railroads and the competing transportation service may influence the demand for grain barge transportation. Grain producers in Iowa or Minnesota may find Pacific Northwest ports (PNW) an alternative to lower Mississippi River ports. Therefore, grain demand at Pacific Northwest (PNW) ports and transportation rates linking the Upper Mississippi hinterland and the PNW may impact grain barge demand on the Upper Mississippi River. In addition, the spread between ocean freight rates from the Pacific Northwest and lower Mississippi River ports to Asia may impact grain barge demand on these waterways.

**Model Specifications**

Based on the theory discussion above, we suggest important forces affecting grain barge demand on the Upper Mississippi River. The grain barge demand function is specified as:

$$q_{b,t} = f\left(q_{b,t-i}, p_{b,t}, exd_{g,t}, domd_{g,t}, doms_{g,t}, p_{o,t}, D_t\right) \quad (4.1)$$

where $q_{b,t}$ is the quantity of the grain transportation service purchased by river grain shippers per unit of time t, $p_{b,t}$ is the grain barge rate, $exd_{g,t}$ is the grain export level, and $domd_{g,t}$ and $doms_{g,t}$ are the domestic demand and supply of grain, respectively. The variable $p_{o,t}$ is the rate proxy of other transportation modes and $D_t$ are weather-related and seasonal dummy variables.

Grain barge movement on the Upper Mississippi and Illinois Rivers exhibits significant seasonality (Figures 4.2 and 4.3); therefore, the quantity of grain moved by barge in previous time periods (either one month or one year past) may provide useful information for the current barge demand. In general, this dynamic relationship can be formulated as an autoregressive distributed lag (ADL) model. Typically, an ADL ($m$, $n$) model represents an equation with $m$ lags of the dependent variable and $n$ lags of the independent variable as regressors. In this study, we attempt to explore the influence of previous barge demand on the current demand, hence, the lag of the dependent variable, $q_{b,t}$, is included in the demand equation. The demand equation then becomes a partial adjustment model: a special case of ADL model (Davidson and MacKinnon). Furthermore, the lagged structure facilitates the estimation of long-run relationships.

Most obviously, barge rates should be included as an explanatory variable. According to the law of demand, an inverse relationship should exist between barge demand and rate, that is, an increase in the grain barge rate will reduce grain barge demand, *ceteris paribus*. Clearly, foreign grain demand would appear to have an important impact on the demand for grain barge transportation since 95+ percent of grain barge movements on the Upper Mississippi and Illinois Rivers are to lower Mississippi

River ports. An increase in foreign grain demand will shift the grain barge demand curve to the right, hence a positive relationship between foreign grain demand and the derived transportation demand. The domestic supply and demand of grain in the north central region is influential in determining grain barge usage. Regional grain supply is expected to affect the derived barge transport demand in a positive manner since an increase in local grain supply will shift the excess supply curve and the grain barge demand curve rightward. In contrast, an increase in regional grain demands will have a negative impact on grain barge transport demand due to the leftward shift of the excess grain supply curve and derived transport demand.

Other transportation modes may also impact grain barge traffic on the UMR-IWW. For instance, a north-south railroad (e.g., ICG now CN) linking the north central region to lower Mississippi River ports may offer strong competition to the grain barge fleet operating on the Upper Mississippi and Illinois Rivers. Similarly, selected railroads (Burlington Northern-Santa Fe and Union Pacific) operating in Minnesota and Iowa may compete with the barge industry through their links to Pacific Northwest (PNW) ports. Potentially, a(n) reduction (increase) in rail rates to the PNW will increase (decrease) rail grain shipments to the Pacific Northwest, therefore, reducing (increasing) the amount of grain shipped by barge on the inland waterways. Railroads and trucks may also complement barge transportation since they are typically used to transport grain to the River. If the rate associated with complementary rail or truck grain carriage increases, it is likely that the quantity of grain shipped to the River will diminish. Accordingly, the demand for grain barge traffic would decrease or shift to the left. Conceptually, ocean carrier transportation rates may also influence grain barge demand on the UMR-IWW. A relatively high ocean freight rate linking lower Mississippi River ports to world importing regions may adversely affect grain barge demand on the Upper Mississippi and Illinois Rivers, whereas comparatively low ship rates may increase grain barge demand.

Obviously, floods and droughts impact the navigability of the inland waterway. When a flood or drought occurs, barge demand may be weakened. Similarly, grain barge demand may be influenced by seasonal factors. During the grain harvest season, the demand for grain barge service may increase. In the winter season, the Upper Mississippi River is typically not navigable so grain barge demand will be nonexistent. In contrast, the Illinois River is generally navigable during the winter and may experience an increase in grain barge traffic because of the closure of the Upper Mississippi River.

**Variables and Data**

This section offers a brief discussion of selected variables used to measure grain barge demand on the UMR-IWW. Data to estimate these relationships is monthly and extends from 1992 through 1999. Table 4.1 relates the definition of variables included in the study. The descriptive statistics for continuous variables are presented in Table 4.2. The upper portion of both tables includes variables used in the estimation of the upper Mississippi River's grain barge demand while the middle portion includes variables used in the estimation of the Illinois River's model. The variables listed in the lower portion of the table are included in both Rivers' grain barge demand equations. Following is a discussion of variables included in the Upper Mississippi and Illinois River's grain barge demand equations.

***Upper Mississippi River***

Variables to estimate the Upper Mississippi River's grain barge demand equations included the following: (1) quantity of grain shipped by barge per month and its lagged term (BQUM), (2) two lagged dependent variables ($BQUM_{t-1}$ and $BQUM_{t-12}$)[5], (3) grain barge tariff rate (BRNI), (4) export grain demand at the lower Mississippi River ports (GEXPQ), (5) domestic grain demands (TCDOM), (6) regional grain supply (GSTOCKUM), (7) rates of competing and complementary transportation modes (OCEANS, RRMR, RRPNW), and (8) dummy variables (CLOSURE, FLOOD). BQUM represents the quantity of grain shipped per month from the Upper Mississippi River to the lower Mississippi River port area. It is grain that originated on that segment of the Mississippi River extending from Minneapolis to Lock 24. These unpublished data were generated by the Tennessee Valley Authority and provided by the Agricultural Marketing Service (AMS), U.S. Department of Agriculture (USDA). Corn and soybeans are the primary grains shipped by barge on the Upper Mississippi River. Figure 2 shows monthly grain shipments on the Upper Mississippi River over the study period: peak

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[5] The length of lag is determined by the Schwartz criterion (Schwartz). Based on the Schwartz test statistic, we select one- and twelve-lag of dependent variables in the model. Those two lagged dependent variables present some economic meanings within the context of barge transportation. The first lagged dependent variable, $BQUM_{t-1}$, is used to measure the influence of barge movement in previous month, while the second lagged dependent variable, $BQUM_{t-12}$, is included to evaluate the seasonality pattern that evolved every twelve month (Figure 4.2).

flows typically occur during the spring and fall seasons. The north Iowa grain barge rate (BRNI) was adopted as a proxy for barge rates linking the Upper Mississippi River to lower Mississippi River ports. It is a spot grain barge rate collected by AMS, USDA by surveying barge industry personnel (USDA/AMS, 2003). The BRNI rate is unavailable in the winter since the River is closed to navigation. The Upper Mississippi River grain barge rate has strong seasonality with the peak rate often occurring between September and November (Figure 4). The average north Iowa grain barge rate is $10.40 per ton, and grain shipments on the Upper Mississippi average 1.7 million tons per month (Table 2).

Grain exports at lower Mississippi River ports (GEXPQ), provided by AMS, USDA (USDA/AMS, 2003), served as a proxy for foreign grain demand. The average quantity of grain exported per month at lower Mississippi River ports is 4.6 million tons (Table 4.2). Corn is the primary grain produced in the Corn Belt and it is exported primarily to lower Mississippi River and Pacific Northwest ports.

Grain stocks in Minnesota and Iowa (GSTOCKUM) represent regional grain supplies. These data were obtained from the Economic Research Service, USDA (USDA/ERS, 2003). Grain stocks are recorded quarterly, hence the need to interpolate the quarterly statistics for purposes of generating monthly values. The combined mean grain stock levels in Minnesota and Iowa were about 52.5 million tons per month (Table 2). Domestic demand for corn and soybeans was represented in the estimated grain barge equation by total domestic corn consumption (TCDOM). Domestic corn consumption (TCDOM) represents all corn consumed in the U.S. (USDA/ERS, 2003)

Transportation rates of complementary and competing transportation modes are also included in the grain barge demand equation. The spread or difference in the U.S. Gulf-to-Japan and the PNW-to-Japan ocean grain freight rates (OCEANS) is included and is calculated by subtracting the PNW rate-to-Japan from the U.S. Gulf-to-Japan rate. In addition, railroad rates from Minnesota origins to Upper Mississippi River elevators (RRMR) and from west Minnesota to the PNW (RRPNW) are included. Data on grain ship rates came from the AMS, USDA (USDA/AMS, 2003) while the unpublished annual Carload Waybill Sample ranging between 1992 and 2001, provided by the AMS, was the source of railroad rates. Rail service from Minnesota origins to the Upper Mississippi River elevators is viewed as complementary to barge transportation (RRMR) while railroad rates from west Minnesota to the PNW (RRPNW) offer competition to grain barge demand. The railroad rates for grain shipments from Minnesota or Iowa to the Mississippi Gulf is not included here since over 90 percent of the export destined grain at the Mississippi Gulf is transported via the Mississippi River from the north central production region (USDA/AMS, 2003). This phenomenon is supported by the limited rail movements in the Waybill data from the north central region to lower Mississippi River ports. Hence, it is likely that the influence of these rail rates on barge demand is modest.

The flood dummy variable (FLOOD) is included to capture the impact of floods on grain barge demand. In general, the entire River will not close if floods occur in a particular region; however, a regional flood may cause some locks to be inaccessible, which may divert the demand from barge to other modes. This dummy variable is generated from the Rock Island District's Flood Information, available at the Navigation Information Connection of the U.S. Army Corps of Engineer (USACE, 2003). A value of 1.0 is included for those months when floods are recorded, while a 0 represents remaining months. The river closure dummy variable (CLOSURE) is used to present the impact of the closure of the Upper Mississippi River, generally from the mid-December to early-March, on grain barge demand.

***Illinois River***

Variables in the Illinois River grain barge demand equation include the following: (1) quantity of grain shipped by barge per month (BQIL), (2) one lagged dependent variable ($BQIL_{t-12}$), (3) grain barge tariff rate (BRSP), (4) export grain demand at the lower Mississippi ports (GEXPQ), (4) regional grain supply (GSTOCKIL), (5) regional grain demands (CNILP), and (6) rates of other transportation modes (OCEAN, RRGF). BQIL is the monthly quantity of grain shipped by barge on the Illinois River: these data were prepared by TVA and provided by the AMS, USDA. During the study period, no trend was evidenced regarding Illinois River grain flow, however, seasonality was observed with peak shipments occurring during the fall and winter seasons (Figure 4.3). An average of 1.3 million tons of grain was transported per month by barge on the Illinois River during the study period. The south of Peoria grain barge rate (BRSP) is used as a proxy of grain barge rates on the Illinois River. The grain barge rate data were collected and made available by AMS, USDA. The south of Peoria barge rate did not show a trend during the study period, however, seasonality in rate was displayed (Figure 4.5). Plots of the south of Peoria barge rate (BRSP) and the north Iowa barge rate (BRNI) show they moved in a parallel manner during the study period (Figures 4.4 and 4.5), however, the average north Iowa barge rate was about one-third higher than the south of Peoria rate (Table 4.2).

Similar to the Mississippi River equation, grain exports at lower Mississippi River ports (GEXPQ) served as a proxy for export demand. Grain stocks in Illinois (GSTOCKIL) represent the regional supply of grain in that state. It is recorded quarterly by the ERS, USDA and was converted to a monthly series for purposes of carrying out this study (USDA/ERS, 2003). The average stock of grain in Illinois during the study period was about 25 million tons (Table 4.2). Proxy for domestic/local grain demand for the Illinois River grain barge demand model is an elevator corn price in central Illinois (CNILP). The demand for corn is strong in this region due to a great amount of grain processing plants located. Therefore, the local price instead of total domestic corn consumption is employed for Illinois barge demand equation.

Transportation rate information on other modes was also included in the Illinois River grain barge demand models. These included the ocean grain freight rate from the U.S. Gulf to Japan (OCEAN) and railroad rates associated with corn and soybean traffic from Illinois origins to lower Mississippi River ports (RRGF). Ocean grain freight data came from AMS, USDA while railroad rate data was from the annual Carload Waybill Sample. Because the Illinois River is navigable year-round, its grain traffic in the winter season is expected to be comparatively high due to the closure of the Upper Mississippi River in that time period. Hypothetically, when the Upper Mississippi River is closed in the Mid-December, those towboats and barges will move out of the Upper Mississippi and up to the Illinois River. The traveling and loading time for those towboats and barges may extend 2-3 weeks. Therefore, the winter dummy generated here is for January, February, and March, one month lag to the CLOSURE dummy in the Mississippi equation.

**Methodology and Results**

To estimate the structural demand equation for grain barge transportation on the Upper Mississippi and Illinois Rivers, both ordinary least squares (OLS) and two-stage least squares (2SLS) are employed. This is done because of the concern regarding the endogeneity of several explanatory variables such as barge rates and rates of other transportation modes. Since equation (4.1) is a demand equation for barge transportation, theoretically, the quantity and the price for barge service are jointly determined. Therefore, a simultaneous bias may occur and barge rates may be correlated with the residual, which makes the OLS estimates biased and inconsistent. Rates of other transportation modes are considered as the potential endogenous variables because their transportation services may react to other's pricing strategies. Results are presented with regard to the Rivers: Upper Mississippi and Illinois Rivers. A Hausman specification test (Hausman) was conducted to compare the OLS and 2SLS estimates and to examine the consistency of OLS estimates. Furthermore, after examining the endogenity of barge demand equation for each River, a barge demand system including both barge demand equations was estimated to test the efficiency of single-equation estimates.

***Upper Mississippi River***

Results of the OLS and associated test will be presented initially, which is followed by the 2SLS estimates. The estimated equations of the likely endogenous variables, including barge rates (BRNI), rail rates of Minnesota to PNW and to the Mississippi River elevators (RRPNW, RRMR), and ocean rates spread between Gulf-Japan and PNW-Japan (OCEANS), in first stage are also presented.

*OLS Estimates*

Several econometrics tests were conducted to examine the quality of the ordinary least square (OLS) results. The residual tests, including correlograms of squared residuals, normality test, serial correlation Lagrange Multiplier (LM) test, autoregressive conditional heteroskedasticity (ARCH) LM test, and White's heteroskedasticity test were conducted for the grain barge demand models. The estimated grain barge demand equation generally performed well in the residual test. In addition, the Augmented Dickey-Fuller (ADF) test was applied to the residuals from the ADL equation. The null hypothesis of non-stationarity was rejected (ADF statistic of –3.872)[6], which indicates that the residuals generated from ADL estimation are a stationary series. However, stability tests consisting of the Chow breakpoint test and CUSUM of squares test

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[6] The critical value at 5% significant level of the augmented Dickey-Fuller (ADF) test here is approximately –3.15. The critical value of the ADF test associated with the generated regressors is lower compared to that on original (not generated) data (Granger and Newbold). Although the critical value in this case is lower than that for non-generated regressors, the ADF statistic of –3.872 indicates the residuals from the ADL models do not exhibit non-stationary behavior.

indicate the estimated parameters are not stable across various time periods. The closing of the River during December, January, and February and the absence of rate and shipment data for these months complicate the estimation of the Upper Mississippi River grain barge demand equations.

Table 4.3 includes regression results of the grain barge demand equations for the Upper Mississippi River. The estimated coefficient of each variable, except the dummy variables, is an elasticity. The elasticity measures the percent change in the dependent variable (quantity of grain transported by barge on the River) associated with a one percent change in a right-hand side or explanatory variable. The expected negative relationship between barge rate (BRNI) and the quantity of grain moved by barge on the Upper Mississippi River is observed in the estimated equation. The elasticity of the grain barge rate is – 0.529, indicating grain barge demand is inelastic with respect to grain barge rate. The t-statistic associated with the BRNI variable (-1.78) indicates that barge rate is statistically significant at the 10 percent level. The quantity of grain exported at lower Mississippi River ports (GEXPQ) affects grain barge demand in a positive manner and is significant at the one percent level. The estimated elasticity of 1.376 implies that a one percent increase in the export grain demand will generate more than a one percent increase in grain barge demand. As expected, there is a positive relationship between lagged grain ending stocks in Minnesota and Iowa (GSTOCKUM) and grain barge demand on the Upper Mississippi River. The GSTOCKUM variable was not statistically significant. Total domestic corn consumption (TCDOM) representing domestic corn demand has a negative influence on grain barge demand and is not statistically significant.

The positive relationship between railroad rates from Minnesota to Pacific Northwest ports (RRPNW) and grain barge demand is as expected: it suggests that a higher railroad rate to the PNW will divert grain exports from the PNW to the Upper Mississippi River barge fleet. However, the influence of RRPNW on grain barge demand is not statistically significant. An increase in the spread between the U.S. Gulf-to-Japan and the Pacific Northwest-to-Japan ocean freight rates (OCEANS) will conceptually make grain exports from lower Mississippi River ports less competitive than exports from the PNW. Consequently, the demand for grain barge transportation on the Upper Mississippi River would be reduced with a widening in the ship rate spread, hence a negative sign is expected and observed on the OCEANS variable. The lack of statistical significance suggests the influence of the ocean freight rate spread may be modest. The RRMR variable has the expected negative sign and is significant at the 5 percent level. The estimated elasticity of the RRMR variable is – 0.904 indicating that a one percent increase in RRMR will lower quantity of grain transported on the River by about 0.9 percent.

The Upper Mississippi River is not navigable in December, January, and February. As a result, the grain barge demand would be expected to dramatically decline in this period. Results confirm this expectation. The CLOSURE variable is highly significant (one percent level) and with a negative sign. The flood variable (FLOOD), a dummy variable, is used to evaluate the impact of Upper Mississippi River floods on grain barge demand. As expected, the FLOOD variable has a negative sign, and is significant at the 5 percent level.

*2SLS Estimates*

Since BRNI, RRMR, RRPNW and OCEANS are treated as endogenous, identification requires at least four instruments (Baltagi). The instruments must be exogenous variables that are uncorrelated with the residual term in the demand equation. The instrument variables selected for barge rate (BRNI) are a lagged term of barge rate. The lagged barge rate was selected as an instrument since it would not be affected by current barge demand. For the rates of other transportation modes (RRPNW, RRMR, OCEANS), the lagged term of each variable, diesel price, and the wage index for transportation and warehouse industries are the selected instruments. Diesel price (DIESEL) and wage index (WAGE) are shifters of the supply curve for transportation services, thus fitting the *exogeneity* and *relevance* condition necessary for instruments. Diesel price was available at the website of the U.S. Department of Energy (USDOE/EIA) while the wage index was collected through the Bureau of Labor Statistics at the U.S. Department of Labor (USDOL/BLS).

The 2SLS estimates of the grain barge demand equations are reported in Table 4.4. The sign of each variable in the demand equation remained the same except the RRPNW variable. The barge rate (BRNI) elasticity decreased to –0.455 and became insignificant. The elasticity of grain exports at lower Mississippi Gulf ports (GEXPQ) decreased modestly from 1.376 to 1.367, and remains significant at the 1 percent level. The elasticity associated with the regional grain stocks variable (GSTOCKUM) increased more than double (0.035 to 0.077) but was non-significant as was the total domestic corn consumption (TCDOM). Interestingly, the rates for other transportation modes were not significant. Thus, grain exports, winter season and flood dummy variables are the only unlagged explanatory variables that significantly influenced barge demand.

Tables 4.5 to 4.8 give the results of the first-stage regression of BRNI, RRMR, RRPNW and OCEANS, respectively. The purpose of presenting those first-stage regressions is to check the validity of selected instruments for each of those potential endogenous variables. If instruments explain very little of the variation in endogenous variables, the so-called *weak instruments* can make the 2SLS estimator biased (Stock and Watson). Stock and Watson give a Rule of Thumb for checking the weak instruments: "*when there is a single endogenous regressor, a first-stage F-statistic less than 10 indicates that the instruments are weak.*" (p. 350). In this equation, there are four potential endogenous variables; hence, the situation will be even more complicated. However, this Rule of Thumb will be applied to offer some basic ideas of how valid those instruments are. For BRNI equation in Table 4.5, three instruments, lagged BRNI ($BRNI_{t-1}$), diesel price (DIESEL), and wage index (WAGE), are statistically significant and the *F*-statistic is 15.62, which indicates those instruments are not weak. The *F*-statistic associated with the OCEANS equation (Table 4.6) is 35.50 and three instruments (lagged BRNI, lagged OCEANS, DIESEL) are statistically significant. For two rail rates equations (RRPNW, RRMR), the *F*-statistic does not exceeds 10 (Tables 4.7 and 4.8) even lagged term of rail rates are statistically significant. The weak instruments for RRPNW and RRMR can likely affect the performance of 2SLS estimators, which can be evaluated from the following test.

The purpose of the Hausman specification test (Hausman) is to test the hypotheses of bias or inconsistency of an estimator. The null hypothesis of this test is $H_{0;}\, E(u/X) = 0$ versus $H_{1;}\, E(u/X) \neq 0$, where the $u$ is the residual term and the $X$ represents the regressors. Two estimators are needed in order to conduct this test. In this study, the Hausman test is based on the difference between the OLS and 2SLS estimators. Failing to reject the null hypothesis implies that the OLS estimators are consistent. The Hausman test statistic for this model is 1.53 and is asymptotically distributed as $\chi^2_{12}$. This was found to be insignificant, which indicates that the 2SLS and OLS estimates are not significantly different given the choice of instruments and the model specification. Thus, the 2SLS method is not preferred over OLS.

### *Illinois River*

Similar to the Upper Mississippi River, both OLS and 2SLS estimates are conducted and presented. The likely endogenous variables include barge rates of south Peoria (BRSP), rail rates linking Illinois and the Gulf (RRGF) and the ocean rates of Gulf and Japan (OCEAN) for Illinois equation.

#### *OLS Estimates*

The estimated barge demand equation for the Illinois River generally performed satisfactory in all econometric tests, including residual and stability tests. Table 4.9 contains the estimated OLS equation. Results show, as expected, a negative relationship between barge rate (BRSP) and grain barge demand is observed. Further, the own-price elasticity is about –0.236 and significant at the five percent level. Therefore, a one percent increase in the south of Peoria grain barge rate will diminish grain barge demand about 0.24 percent, hence an inelastic relationship between barge rate and quantity of grain transported on the Illinois River. As expected, increasing grain export levels at lower Mississippi River ports (GEXPQ) were found to increase grain barge demand. The GEXPQ variable was found to be statistically significant and to have associated elasticities about 0.762.

The central Illinois corn price (CNILP) was included as a proxy for local grain demand. An increase in CNILP is expected to attract grain to the local grain market and correspondingly reduce grain barge demand on the Illinois River. The expected negative sign is observed in the model with elasticities of –0.426, which is significant at one percent level. Lagged grain ending stocks in Illinois (GSTOCKIL), a proxy for grain supply, has the anticipated positive sign; however, the variable is not significant. Railroad linking Illinois origins and lower Mississippi River ports is a substitute for barge transportation on the Illinois River. Therefore, a positive relationship is expected between railroad rates from Illinois origins to lower Mississippi River ports (RRGF) and grain barge demands on the Illinois River. An unexpected negative cross-price elasticity is shown in Table 4.9; however, the variable is not statistically significant.

The influence of the U.S. Gulf-to-Japan ocean freight rate (OCEAN) is evaluated here. Conceptually, increasing ocean freight rates originating from the Gulf will disfavor the lower Mississippi ports which consequently will reduce the grain movement on the Illinois River. Unexpectedly, the sign on the OCEAN variable is positive and statistically significant in the equation. The hypothesis of the positive sign may result from strong demand of export market moving up the export quantity, which simultaneously increasing both grain moved by barge on the River along with the ocean freight rates. The other likely reason of the increasing grain movement on the Illinois River is the destination of those river-moved grains may switch from export markets to Memphis, which is an important hub to transfer the Midwest grain to the southeast feeders. Therefore, the rising ocean rates of Gulf to Japan may increase grain movement on the Illinois River

Results show the winter season variable (WINTER), a dummy variable, to be positive and significant at the one percent level. Thus, statistical results confirm that the Illinois River grain barge demand shifts to the right or increases during the winter period.

*2SLS Estimates*

Considering BRSP, OCEAN and RRGF as endogenous, the instruments used for the first-stage regression include lagged information of those three transportation rates, diesel price and wage index.

Table 4.10 summarizes the 2SLS estimates of the grain barge demand equations. The sign of each variable in the demand equation remained identical comparing to the OLS estimates. The barge rate (BRNI) elasticity increased to –0.241, however, became insignificant. The elasticity of grain exports at lower Mississippi Gulf ports (GEXPQ) increased to 0.808, and remained significant at the 1 percent level. The local grain price

(CNILP) had a lower elasticity, from -0.426 to -0.364, but was still significant at 10 percent level. The elasticity associated with the regional grain stocks variable (GSTOCKIL) was non-significant as was the rates for other transportation modes.

The respective result associated with the first-stage regression of BRSP, OCEAN, and RRGF are presented in Tables 4.11 to 4.13. For BRSP equation in Table 4.11, all five instruments, lagged BRSP ($BRSP_{t-1}$), lagged RRGF ($RRGF_{t-1}$), lagged OCEAN ($OCEAN_{t-1}$), diesel price (DIESEL), and wage index (WAGE), are statistically significant and the *F*-statistic is 22.53, indicating those instruments are well relevant to BRSP. In Table 4.12, the *F*-statistic associated with the first-stage regression of OCEAN equation is 111.08 and three instruments (lagged OCEAN, DIESEL, and WAGE) are statistically significant. Similar to the Upper Mississippi River equation, the rail rates equation (RRGF) has a low *F*-statistic which does not exceeds 10 (Table 4.13). The weak instruments for RRGF can possibly have negative effects on the 2SLS estimators.

The Hausman test was also carried out here to compare the specification of OLS and 2SLS. The test statistic for this model is 1.24 and is asymptotically distributed as $\chi^2_9$. Again, it is statistically insignificant, which indicates that the 2SLS and OLS estimates are not significantly different given the choice of instruments and the model specification. Thus, the OLS method is also preferred over 2SLS for Illinois River grain barge demand equation.

***Single-equation vs. System Estimation***

Although both grain barge demand equations are exempt from the endogenity problem, the efficiency of the OLS estimates is still uncertain. The argument is that some omitted variables or information may affect grain movement on the Upper Mississippi as well as Illinois River. In other words, the residuals generated from the barge demand equation for Mississippi are correlated with that from Illinois River barge demand equation. For example, weather in the Midwest can possibly affect grain quantity moved on both Rivers. If the covariance of the residuals generated from two demand equations is not statistically different from zero, a seemingly uncorrelated regression (SUR) should be employed since the OLS estimates become inefficient. The Zellner's SUR model was adopted here and the covariance matrix of the residuals generated from two barge demand equations is presented in Table 4.14. The covariance of residuals from BQMN and BQIL equations is about 0.008, which exhibit a very modest correlation of those two residuals. A likelihood ratio test was carried out and the null hypothesis is $\sigma_{ij} = 0$. Surprisingly, the test statistic is 0.274 and is asymptotically distributed as $\chi_1^2$, which fails to reject the null hypothesis. Hence, the OLS estimates for both demand equations are efficient.

Since the OLS estimates were found to be consistent and efficient, additional attention is focused on the grain barge demand price elasticity. The grain barge demand elasticities presented in Tables 4.3 and 4.9 are viewed as short-run elasticities. Because the estimated demand equation is an autoregressive distributed lag model we can examine how barge rate (BRNI, BRSP) affects the demand for barge transportation in the long run following the procedure of Davidson and MacKinnon. By using the estimated coefficients of the lagged terms of the dependent variable in demand equation, respective long-run grain barge demand price elasticities were obtained for the Upper Mississippi and Illinois Rivers. For Upper Mississippi River (Table 3), short-run own-price elasticity was estimated to be –0.529 while the calculated long-run price elasticity was –1.118 [-0.529/(1-0.223-0.304)], implying that a one percent increase in the grain barge rate will reduce grain barge demand about one percent in the long run. The short-run own-price elasticity of Illinois River barge demand was -0.236 (Table 9) and the calculated long-run price elasticity was -0.365 [-0.236/(1-0.762)], indicating the barge demand is still inelastic in the long run.

**Concluding Remarks**

The Upper Mississippi River and Illinois Waterway is a critical artery in the U.S. inland waterway system and of great importance to U.S. agriculture. Knowledge of grain barge demand on the River is important to the barge industry, grain producers and authorities that maintain and manage the lock system on the River. It is particularly critical today due to the controversies regarding the expansion of the aged lock system on the River. Economic benefits from inland waterway transportation improvements should be based on demand schedules representing the willingness to pay for improved navigability of the waterway. The areas under the demand function measure the gross benefits from waterway improvement. The purpose of this study is to estimate grain barge demand for the Upper Mississippi and Illinois Rivers and develop an improved understanding of forces impacting the demand.

Some notable findings are reported in this paper. Barge rates have a negative effect on grain barge demand or the quantity of grain transported by barge from Upper Mississippi River origins to lower Mississippi River ports. A one percent increase in the grain barge rate will lower quantity transported by barge an estimated 0.5 percent in the short-run. For a long-run perspective, the own-price elasticity is elastic (-1.015) under the *ceteris paribus* assumption. The negative own-price elasticity of grain barge demand is also observed for Illinois River. A one percent increase in the barge rate of south Peoria will reduce the grain movement on the Illinois River about 0.2 percent in the short-run. Give the *ceteris paribus* assumption, the elasticity increases to -0.365 percent in the long-run.

Foreign grain demand, as measured by quantities of grain exported at lower Mississippi River ports, has an important influence on grain barge demand for both Rivers. This is reasonable since grain barge demand is a derived demand that depends on excess demands associated with the international grain market. The export demand elasticity was found to be elastic (1.197) for the Upper Mississippi River grain barge demand while inelastic (0.762) for the Illinois River one. Increases in total domestic corn consumption is negatively related to quantities of grain transported by barge on the Upper Mississippi River, the elasticity, however, was not statistically significant. In contrast, a one-percent positive shock in local corn prices can reduce about -0.4 percent of the grain barge demand on the Illinois River.

Competing and complementary transportation modes may have an affect on Upper Mississippi and Illinois Rivers grain barge demand; however, the results of this study are not statistically significant regarding most of these modes. For example, lower railroad rates linking Minnesota origins to Pacific Northwest ports was thought to be associated with reductions in grain transport on the Upper Mississippi; however, the influence was not statistically significant. In contrast, the railroad rate linking Minnesota origins to Upper Mississippi River elevators was found to be a statistically important explainer of Upper Mississippi River grain barge demand, with increasing railroad rates associated with reduced grain barge movements on the Upper Mississippi River. Ocean grain freight rates were not statistically important explainers of grain barge demand on the Upper Mississippi. Railroad rates linking Illinois and Gulf was expected to have positive impact on grain barge demand since the higher rail rates may divert the grain from rail to barge transportation. The expected positive sign was not observed and the elasticity was not statistically significant. Surprisingly, the positive effect of ocean rates linking Gulf and Japan on grain movement on the Illinois River was observed. A higher ocean rates may generate lower willingness of grain companies to ship their commodity to international markets through the lower Mississippi ports, which accordingly may reduce the grain movement on the Illinois River. The hypothesis of the positive sign in the barge demand equation in this study is that the strong export demand possibly moves both ocean rates and grain movements on the River up. Also the increasing grain volume on the Illinois River may get into Memphis and transfer to the southeast domestic market.

As expected, floods and the winter season have statistically important impacts on Upper Mississippi and Illinois Rivers grain barge demand. Floods on the Upper

Mississippi reduce grain barge demand, as does the winter season when the River is closed to navigation. In contrast, the grain barge demand increases while the Mississippi River is not navigable in the winter.

In summary, grain barge demand on the Upper Mississippi River is influenced by barge rates, foreign grain demands localized to lower Mississippi River ports, the rail rate for Minnesota-originated grain shipped to the Mississippi River, the winter season, and floods. For grain barge demand on the Illinois River, barge rates, export demand at the lower Mississippi ports, hinterland corn prices, the ocean freight rates of Gulf to Japan, and winter season are the shifters of grain barge demand. In general, evaluated complementary and substitute transportation service did not yield statistically significant results.

# CHAPTER V

# CONCLUSIONS

The Upper Mississippi River and Illinois Waterway are the primary transportation channels for moving export-bound grain from the north central U.S. to the Mississippi Gulf port area. Lock congestion on the Upper Mississippi River and Illinois Waterway, however, have generated great concerns regarding the future navigation efficiency on the Waterway and its impact on the competitiveness of U.S. grain in the international market. A feasibility study with respect to expansion of selected locks on the lower reaches of both Rivers has been under way for more than a decade; however, several fundamental issues that are critical to a meaningful estimate of benefits resulting from lock expansion are still unseen. For instance, does lock congestion actually affect grain barge rates on the Waterway? If yes, how much is the impact? Furthermore, how do grain barge rates on the Waterway affect export and domestic grain markets and other transportation mode rates? How do those grain prices and transport costs interact with each other over time? Also, what factors affect demand for grain barge transportation on these two rivers? What are the short-run and long-run price elasticities? The answers to these questions are critical input to measuring the economic benefits from investment on the Upper Mississippi River and Illinois Waterway. This dissertation contributes by exploring these issues and generating more knowledge associated with these questions.

Chapter II identifies and measures the impact of lock congestion on grain barge transportation on the waterway. The focus of the analysis is lock congestion on segments of the Upper Mississippi River and Illinois Waterway grain barge rates that link sections of these Rivers to the Mississippi Gulf ports. Analyses are carried out to model contemporaneous innovation covariance in multivariate time-series models using directed acyclic graphs. Based on tests of data stationarity and lag structure, a one-lag Vector Autoregression (VAR) models, including information on grain barge rates, lock congestion, seasonal factors and traffic levels, was formulated for the Upper Mississippi River and the Illinois River, respectively. Results suggest grain barge rates on both rivers are not affected by lock congestion that occurred in the previous month. In contrast, lock congestion in the lower reaches of the Upper Mississippi and Illinois Rivers in contemporaneous time are found to increase barge rates that link the north central United States to the lower Mississippi Gulf ports; however, the impact of lock congestion on grain barge rates is moderate. This information may offer the public or some interest groups that advocate lock expansion a chance to re-focus on the core of this debate over the lock-expansion issue: does lock congestion really unfavorably influence the competitiveness of U.S. grain in the world grain market?

An additional and important contribution of this research relates to grain barge rate discovery. Directed graph analysis suggested that Minnesota barge rates play a critical role in grain barge rate discovery. Grain shippers in the geographic periphery of the river (Minnesota) appear to bid up barge rates in order to attract empty barges to this portion of the river, which in turn affects grain barge rates in the Iowa portion of the river. It suggests that the marginal or more distant regions may introduce the adjustment in price in order to acquire transport services. In this case, grain barge rates on the

Upper Mississippi River are likely discovered in the Minnesota portion. If this hypothesis is correct, it may imply a priority lockage given to those up-bound empty barges may increase equipment supply and reduce barge transportation rates for Minnesota grain shippers, which provides a non-structural alternative to alleviate the impact of lock congestion on grain business.

Chapter III explores the interaction between grain prices in export and domestic markets and transportation rates linking these markets over time. In particular, how do grain barge rates on the Upper Mississippi River and Illinois Waterway affect other grain prices and transportation rates? Previous studies generally lacked a dynamic perspective or failed to consider alternative transportation modes. This research amends those shortcomings by evaluating the dynamic interrelationships among grain prices, transportation rates, and export volumes in three model frameworks using time-series analytical mechanisms incorporating directed acyclic graphs. Some consistent results are observed throughout all three models. In general, shocks in transportation rates (barge, rail, and ocean) explain a considerable proportion of the variation in corn and soybean market prices in the long run, suggesting the importance of transportation in grain price determination. Among three transportation modes, the volatile ocean freight rates are the most important transport cost contributing to the variation in grain prices. The influence of barge rates on the Upper Mississippi River and Illinois Waterway on the variation in grain prices is quite sensitive to the model specification, while the three rail rates consistently explain less than 10 percent of the variation in grain prices. The dynamic interrelationships among the six evaluated transportation rates are also found, which shows the expected competition and cooperation within various transportation modes. One interesting finding here is that a significant portion of the variation in the rail rates linking Minnesota and the Pacific Northwest ports is explained by the ocean rates linking the Mississippi Gulf and Japan. Since Minnesota is on the market boundary between the Pacific Northwest ports and Gulf ports, the rail rates from Minnesota to Pacific Northwest ports and ship rate to Japan are theoretically related to the Minnesota grain barge rates plus the ship rate from Gulf to Japan. The oligopolistic railroads may observe these relationships and adjust their prices in regard to shocks in barge rates and ocean rates, a finding confirmed in this study. In the study of market integration, results indicate that the north central corn markets (Minnesota and Iowa) likely have the most influence on other markets, while the Gulf soybean export price dominates the soybean market in the long run.

Chapter IV estimates the structural demand for grain barge transportation for both the Upper Mississippi and Illinois Rivers. Knowledge of barge demand is particularly critical today due to the controversies regarding the expansion of the aged lock system on both rivers since it offers perspective on forces that influence quantity of grain entering the river for transport. Policy analysts considering an investment for locks and dam renovation must understand what factors attract grain shippers to select barge transportation over other modes or markets. This research provides the first direct estimate of grain barge demand on the Upper Mississippi River and Illinois Waterway. As expected, results suggest foreign grain demand is the most influential force impacting grain barge demand on both rivers. Hence, the grain exports over the next several decades play an important role in determining the value of these expensive transportation infrastructure improvements. It also implies the projected grain traffic levels on the river will account for a considerable weight in determining the benefits of expanding the locks and dam system. Additionally, results indicate an inelastic demand for grain barge transportation on the Upper Mississippi in the short run; demand is price elastic in the long run. The price elasticity for grain barge demand on the Illinois River is consistently inelastic. The comparative high price elasticities on Mississippi River relative to elasticities on the Illinois River may result from the geographic location. Grain produced in Minnesota and Iowa can be shipped to Pacific Northwest ports and Mexico border in addition to Gulf ports; while the Gulf ports are the primarily export destination for Illinois grain. Therefore, the impact of barge rate change on the grain quantity on the Illinois River is small relative to that on the Upper Mississippi River. Moreover, the negative impact of increasing local corn prices on river grain flow is observed. This implies that increasing local demands for corn (e.g. ethanol production) could eventually direct more corn to domestic markets, thus lowering the value of the rivers for commercial navigation. Also, the winter season and floods negatively affect demand on the Upper Mississippi, while grain barge demand increases on the Illinois River during the winter. In general, evaluated complementary and substitute transportation service to barge transport did not yield statistically significant results.

The work completed here is a beginning to a complicated process associated with a feasibility study. The outputs generated in each Chapter can be used as parameters for the benefit-and-cost analysis. In addition, there are several opportunities for future work.

For instance, lock congestion on the lower reaches of Upper Mississippi River and Illinois Waterway was found to affect barge rates in Chapter II. However, which lock in that segment has the most influence on barge rates? Given the limited resources available, which individual lock needs expansion the most? In Chapter III, the dynamic interactions between grain prices, transportation rates, and grain exports are evaluated. Due to a degrees of freedom problem, only two export quantity variables are included. With more observations, it would be important to include domestic grain consumption to fully explore the interactions over time. Also, cointegration analysis was conducted and twelve cointegration vectors among the sixteen evaluated series were found. It would be interesting to explore the likely structure of those twelve cointegration vectors. In Chapter IV, emerging ethanol production and Mexico-U.S. grain trade are not taken into account regarding their effect on barge demand due to incomplete data. This area deserves further study when data are available.

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# APPENDIX A

## TABLES

**Table 1.1 Characteristics of Locks on the Upper Mississippi River and Illinois Waterway**

| | Upper Mississippi River | | | | |
|---|---|---|---|---|---|
| Lock name or number | River Mile | Year Opened | Width | Length | Lift |
| Upper St. Anthony Falls | 853.9 | 1963 | 56 | 400 | 49 |
| Lower St. Anthony Falls | 853.3 | 1959 | 56 | 400 | 25 |
| 1 Main Chamber | 847.6 | 1930 | 56 | 400 | 38 |
| 1 Aux. Chamber | 847.6 | 1932 | 56 | 400 | 38 |
| 2 Main Chamber | 815.0 | 1930 | 110 | 500 | 12 |
| 2 Aux. Chamber | 815.0 | 1948 | 110 | 600 | 12 |
| 3 | 769.9 | 1938 | 110 | 600 | 8 |
| 4 | 752.8 | 1935 | 110 | 600 | 7 |
| 5 | 738.1 | 1935 | 110 | 600 | 9 |
| 5A | 728.5 | 1936 | 110 | 600 | 5 |
| 6 | 714.0 | 1936 | 110 | 600 | 6 |
| 7 | 702.0 | 1937 | 110 | 600 | 8 |
| 8 | 679.0 | 1937 | 110 | 600 | 11 |
| 9 | 647.0 | 1938 | 110 | 600 | 9 |
| 10 | 615.0 | 1936 | 110 | 600 | 8 |
| 11 | 583.0 | 1937 | 110 | 600 | 11 |
| 12 | 556.0 | 1938 | 110 | 600 | 9 |
| 13 | 522.0 | 1938 | 110 | 600 | 11 |
| 14 Main Chamber | 493.3 | 1939 | 110 | 600 | 11 |
| 14 Aux. Chamber | 493.1 | 1922 | 80 | 320 | 11 |
| 15 Main Chamber | 482.9 | 1934 | 110 | 600 | 16 |
| 15 Aux. Chamber | 482.9 | 1934 | 110 | 600 | 16 |
| 16 | 457.2 | 1937 | 110 | 600 | 9 |
| 17 | 437.1 | 1939 | 110 | 600 | 8 |
| 18 | 410.5 | 1937 | 110 | 600 | 10 |
| 19 | 364.2 | 1957 | 110 | 1200 | 38 |
| 20 | 343.2 | 1936 | 110 | 600 | 10 |
| 21 | 324.9 | 1938 | 110 | 600 | 10 |
| 22 | 301.2 | 1938 | 110 | 600 | 10 |
| 24 | 273.4 | 1940 | 110 | 600 | 15 |
| 25 | 241.4 | 1939 | 110 | 600 | 15 |
| 26 Melvin Price | 200.8 | 1990 | 110 | 1200 | 24 |
| 26 Melvin Price Aux. Chamber | 200.8 | 1992 | 110 | 600 | 24 |
| 27 | 185.1 | 1953 | 110 | 1200 | 21 |
| 27 Aux. Chamber | 185.1 | 1953 | 110 | 600 | 21 |
| | Illinois River | | | | |
| Thomas J. O'Brien | 326.5 | 1960 | 110 | 1000 | 4 |
| Lockport | 291.1 | 1933 | 110 | 600 | 40 |
| Brandon Road | 286.0 | 1933 | 110 | 600 | 34 |
| Dresden Island | 271.5 | 1933 | 110 | 600 | 22 |
| Marseilles | 244.6 | 1933 | 110 | 600 | 24 |
| Starved Rock | 231.0 | 1933 | 110 | 600 | 19 |
| Peoria | 157.7 | 1939 | 110 | 600 | 11 |
| LaGrange | 80.2 | 1939 | 110 | 600 | 10 |

**Table 2.1. Statistical Summary of Accumulated Barge Delays, Barge Rates, and Traffic Volumes on Upper Mississippi and Illinois River Segments, 1980-1999**

| | Obs. (N) | Mean | Standard Deviation | Min | Max |
|---|---|---|---|---|---|
| Upper Mississippi Delay (hrs) | | | | | |
| L1_L8[1] | 179 | 6.97 | 6.125 | 0.00 | 54.00 |
| L9_L17[2] | 179 | 13.05 | 7.010 | 3.18 | 55.40 |
| L18_L27[3] | 179 | 29.08 | 19.295 | 5.70 | 125.76 |
| Illinois River Delay (hrs) | | | | | |
| TOB_SR[4] | 240 | 11.44 | 11.322 | 0.65 | 141.68 |
| PEO_LA[5] | 240 | 6.32 | 10.126 | 0.00 | 102.73 |
| LMP_L27[6] | 240 | 8.79 | 11.648 | 1.14 | 102.50 |
| Barge Rate ($/ton) | | | | | |
| BRSM[7] | 179 | 11.24 | 3.577 | 5.22 | 23.33 |
| BRNI[8] | 179 | 9.39 | 2.891 | 5.06 | 19.13 |
| BRSP[9] | 240 | 7.41 | 2.442 | 3.54 | 15.76 |
| Traffic Volume (counts) | | | | | |
| TOTBG25[10] | 179 | 3,900.60 | 840.619 | 1,509.00 | 5,737.00 |
| TOTBGLA[11] | 240 | 2,705.97 | 675.127 | 109.00 | 5,096.00 |

[1] Accumulated lock delay at lock 1 through lock 8.
[2] Accumulated lock delay at lock 9 through lock 17.
[3] Accumulated lock delay at lock 18 through lock 27.
[4] Accumulated lock delay at the Thomas O'Brien lock through Starved Rock lock.
[5] Accumulated lock delay at the Peoria lock and the LaGrange lock.
[6] Accumulated lock delay at the Melvin Price lock and lock 27.
[7] South Minnesota barge rate.
[8] North Iowa barge rate.
[9] South of Peoria barge rate.
[10] Total number of barges passing through lock 25.
[11] Total number of barges passing through the LaGrange lock.

**Table 2.2. Tests for Non-Stationarity of Levels of Barge Rates, Lock Delays and Traffic Volumes from Upper Mississippi and Illinois Rivers**

| Series* | t-test (k) |
|---|---|
| Upper Mississippi River | |
| BRSM | -6.03 (1) |
| BRNI | -7.03 (1) |
| L1_L8 | -11.18 (0) |
| L9_L17 | -9.16 (0) |
| L18_L27 | -6.19 (1) |
| TOTBG25 | -7.43 (0) |
| Illinois River | |
| BRSP | -6.75 (1) |
| TOB_SR | -10.39 (1) |
| PEO_LA | -11.85 (0) |
| LMP_L27 | -7.93 (1) |
| TOTBGLA | -9.61 (0) |

* See Table 2.1 for definition of variables.

Note: Critical values are given in Fuller (1976). The 5% critical value is –2.89. We reject the null for observed t values less than this critical value. The number in parenthesis reflects the number of lags (k) of the dependent variable in the Augmented Dickey-Fuller test. Here k is selected by minimizing Schwarz loss over alternative lags 0, 1, 2, …, 6.

**Table 2.3. Loss Metrics on the Order of Lags (k) in a Levels Vector Autoregression on Barge Rates, Lock Delays and Traffic Volumes on the Upper Mississippi and Illinois Rivers**

| | Lag = k | SL | Φ |
|---|---|---|---|
| Upper Mississippi River | | | |
| | 0 | 29.414 | 28.818 |
| | 1 | 28.572* | 27.578* |
| | 2 | 29.369 | 27.977 |
| | 3 | 29.958 | 28.168 |
| | 4 | 30.620 | 28.652 |
| | 5 | 31.697 | 29.114 |
| Illinois River | | | |
| | 0 | 28.751 | 28.213 |
| | 1 | 27.804* | 27.041* |
| | 2 | 28.229 | 27.242 |
| | 3 | 28.761 | 27.550 |
| | 4 | 29.235 | 27.800 |
| | 5 | 29.675 | 28.016 |

* indicates minimum.

Note: The models considered at lags 0 through 5 have a set of seasonal dummy variables. Metrics considered are Schwartz-Loss (SL) and Hannan, and Quinn's Φ measure on lag length of a levels vector autoregression:

$$SL = \log(|\Sigma| + n^*k)(\log T) / T,$$
$$\Phi = \log(|\Sigma| + (2.00)(n^*k)\log(\log T)) / T.$$

Here Σ is the error covariance matrix estimated with n*k+1 (the 1 represents a constant) regressors in each equation, n is the total number of series, T is the total number of observations on each series, the symbol "| |" denotes the determinant operator, and log is the natural logarithm. We select that order of lag that minimizes the loss metric.

**Table 2.4. Granger-type F-test of a Levels Vector Autoregression on Barge Rates, Lock Delays, and Traffic Volumes on the Upper Mississippi and Illinois Rivers**

| | Granger-type F-test (P-values) | | | | | |
|---|---|---|---|---|---|---|
| *Lagged Variables*[*] | *Dependent Variable (Current Values)* | | | | | |
| Upper Mississippi | BRSM | BRNI | L18_L27 | L9_L17 | L1_L8 | TOTBG25 |
| BRSM | 9.87 | 1.80 | 1.28 | 0.28 | 0.27 | 1.51 |
| | (0.00) | (0.18) | (0.26) | (0.60) | (0.60) | (0.22) |
| BRNI | 8.23 | 11.48 | 2.15 | 0.62 | 0.63 | 5.37 |
| | (0.01) | (0.00) | (0.14) | (0.43) | (0.43) | (0.02) |
| L18_L27 | 0.58 | 0.14 | 24.47 | 3.13 | 0.12 | 8.31 |
| | (0.45) | (0.70) | (0.00) | (0.08) | (0.73) | (0.00) |
| L9_L17 | 0.41 | 0.27 | 2.67 | 7.75 | 1.41 | 0.00 |
| | (0.52) | (0.61) | (0.10) | (0.01) | (0.24) | (0.97) |
| L1_L8 | 0.18 | 0.11 | 1.53 | 0.51 | 1.70 | 6.96 |
| | (0.67) | (0.74) | (0.22) | (0.48) | (0.19) | (0.01) |
| TOTBG25 | 1.01 | 0.23 | 1.64 | 3.18 | 2.78 | 37.19 (0.00) |
| | (0.32) | (0.63) | (0.20) | (0.08) | (0.10) | |
| Illinois River | BRSP | PEO_LA | TOB_SR | LMP_L27 | TOTBGLA | |
| BRSP | 284.38 | 0.52 | 4.69 | 0.43 | 3.27 | |
| | (0.00) | (0.47) | (0.03) | (0.51) | (0.07) | |
| PEO_LA | 0.11 | 8.80 | 0.03 | 0.01 | 2.86 | |
| | (0.74) | (0.00) | (0.85) | (0.93) | (0.09) | |
| TOB_SR | 1.34 | 0.00 | 0.02 | 0.04 | 2.02 | |
| | (0.25) | (0.97) | (0.89) | (0.83) | (0.16) | |
| LMP_L27 | 0.42 | 0.54 | 1.29 | 84.68 | 0.94 | |
| | (0.52) | (0.46) | (0.26) | (0.00) | (0.33) | |
| TOTBGLA | 4.69 | 0.35 | 0.73 | 3.61 | 29.81 | |
| | (0.03) | (0.55) | (0.39) | (0.06) | (0.00) | |

[*] See Table 2.1 for definition of variables.

**Table 2.5. Forecast Error Decompositions on Barge Rates, Lock Delays, and Traffic Volumes on the Upper Mississippi River**

| Horizon | Std Error | BRSM* | BRNI | L18_L27 | L9_L17 | L1_L8 | TOTBG25 |
|---|---|---|---|---|---|---|---|
| | | | | ***(BRSM)*** | | | |
| 0 | 1.876 | 94.16 | 0.00 | 5.45 | 0.00 | 0.00 | 0.39 |
| 1 | 2.470 | 89.64 | 3.25 | 6.65 | 0.15 | 0.06 | 0.25 |
| 9 | 3.112 | 86.17 | 5.94 | 6.53 | 0.35 | 0.28 | 0.73 |
| | | | | ***(BRNI)*** | | | |
| 0 | 1.683 | 67.16 | 28.67 | 3.89 | 0.00 | 0.00 | 0.28 |
| 1 | 2.049 | 70.30 | 24.65 | 4.70 | 0.11 | 0.04 | 0.19 |
| 9 | 2.429 | 72.96 | 20.95 | 5.09 | 0.29 | 0.20 | 0.50 |
| | | | | ***(L18_L27)*** | | | |
| 0 | 15.832 | 0.00 | 0.00 | 93.35 | 0.00 | 0.00 | 6.65 |
| 1 | 17.681 | 0.09 | 1.18 | 86.81 | 1.36 | 0.72 | 9.84 |
| 9 | 18.921 | 0.84 | 2.40 | 80.11 | 2.01 | 1.31 | 13.33 |
| | | | | ***(L9_L17)*** | | | |
| 0 | 6.101 | 0.00 | 0.00 | 0.00 | 90.48 | 0.00 | 9.52 |
| 1 | 6.498 | 0.08 | 0.38 | 1.79 | 84.12 | 0.26 | 13.37 |
| 9 | 6.813 | 0.91 | 1.33 | 4.00 | 77.12 | 0.73 | 15.92 |
| | | | | ***(L1_L8)*** | | | |
| 0 | 5.568 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 0.00 |
| 1 | 5.693 | 0.09 | 0.41 | 0.11 | 0.86 | 96.62 | 1.91 |
| 9 | 5.752 | 0.14 | 0.49 | 0.39 | 0.96 | 94.88 | 3.14 |
| | | | | ***(TOTBG25)*** | | | |
| 0 | 593.125 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 |
| 1 | 709.311 | 1.12 | 2.64 | 5.37 | 0.00 | 3.29 | 87.58 |
| 9 | 814.531 | 5.85 | 4.90 | 10.38 | 0.27 | 3.95 | 74.64 |

* See Table 2.1 for definition of variables.

**Table 2.6. Forecast Error Decompositions on Barge Rates, Lock Delays, and Traffic Volumes on the Illinois River**

| Horizon | Std Error | BRSP* | PEO_LA | TOB_SR | LMP_L27 | TOTBGLA |
|---|---|---|---|---|---|---|
| | | | | ***(BRSP)*** | | |
| 0 | 1.222 | 90.21 | 3.52 | 0.00 | 3.66 | 2.61 |
| 1 | 1.542 | 89.60 | 3.93 | 0.39 | 4.43 | 1.65 |
| 12 | 1.927 | 88.53 | 3.61 | 0.43 | 5.54 | 1.89 |
| | | | | ***(PEO_LA)*** | | |
| 0 | 8.977 | 0.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| 1 | 9.192 | 0.09 | 99.57 | 0.00 | 0.23 | 0.10 |
| 12 | 9.228 | 0.37 | 98.98 | 0.00 | 0.45 | 0.20 |
| | | | | ***(TOB_SR)*** | | |
| 0 | 9.485 | 0.00 | 0.00 | 100.00 | 0.00 | 0.00 |
| 1 | 9.565 | 0.86 | 0.10 | 98.33 | 0.22 | 0.49 |
| 12 | 9.631 | 1.97 | 0.20 | 97.02 | 0.26 | 0.55 |
| | | | | ***(LMP_L27)*** | | |
| 0 | 9.051 | 0.00 | 0.00 | 0.00 | 100.00 | 0.00 |
| 1 | 10.327 | 0.06 | 0.01 | 0.02 | 98.68 | 1.23 |
| 12 | 10.812 | 0.18 | 0.12 | 0.03 | 97.22 | 2.44 |
| | | | | ***(TOTBGLA)*** | | |
| 0 | 447.817 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 |
| 1 | 478.229 | 0.53 | 0.89 | 0.82 | 0.15 | 97.60 |
| 12 | 487.358 | 2.83 | 1.03 | 0.88 | 0.34 | 94.92 |

* See Table 2.1 for definition of variables.

**Table 3.1. Descriptive Statistics for Selected Monthly Corn and Soybean Prices, Freight Rates, and Grain Exports 1990 – 2002**

| Variables | Mean | S.D. | Min. | Max. | C.V. |
|---|---|---|---|---|---|
| Corn Prices ($/ton) | | | | | |
| Pacific Northwest (PNW) | 107.47 | 20.96 | 75.18 | 199.70 | 0.20 |
| Mississippi Gulf (GF) | 98.13 | 20.32 | 67.34 | 184.64 | 0.21 |
| Minneapolis (MN) | 83.14 | 20.22 | 52.33 | 172.68 | 0.24 |
| Southeast Iowa (SEI) | 83.22 | 20.68 | 51.20 | 172.77 | 0.25 |
| South Central Illinois (CIL) | 85.89 | 20.54 | 52.91 | 172.83 | 0.24 |
| Memphis (MEM) | 90.02 | 17.52 | 58.05 | 160.75 | 0.19 |
| Soybean Prices ($/ton) | | | | | |
| Mississippi Gulf (SGF) | 206.91 | 33.16 | 153.33 | 297.67 | 0.16 |
| Illinois Processor (SILP) | 197.18 | 33.59 | 142.18 | 292.53 | 0.17 |
| Barge Rate ($/ton) | | | | | |
| South of Peoria (BR) | 7.92 | 2.50 | 4.04 | 15.27 | 0.32 |
| Rail Rates ($/ton) | | | | | |
| IL – Gulf (RIG) | 9.30 | 1.67 | 5.68 | 17.43 | 0.18 |
| MN – PNW (RMP) | 25.76 | 2.05 | 20.26 | 33.46 | 0.08 |
| IL – Memphis (RIM) | 5.90 | 0.71 | 4.59 | 8.07 | 0.12 |
| 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 |
| Export Quantities (1,000 tons) | | | | | |
| Mississippi Gulf (EQG) | 4,721.68 | 1,076.01 | 2,287.21 | 7,310.14 | 0.23 |
| PNW (EQP) | 865.37 | 458.28 | 33.89 | 2,005.99 | 0.53 |

**Table 3.2. Loss Metrics on the Order of Lags (k) in a Levels Vector Autoregression on Two Corn Prices and Barge Rates, 1990-2002**

| Lag | Schwarz-loss | Akaike's AIC | Hannan and Quinn's Φ |
|---|---|---|---|
| 0 | 9.726 | 8.276 | 9.216 |
| 1 | 6.256 * | 4.496 | 5.638 |
| 2 | 6.261 | 4.190 | 5.533 * |
| 3 | 6.476 | 4.094 * | 5.639 |
| 4 | 6.752 | 5.060 | 5.806 |
| 5 | 6.976 | 4.973 | 5.920 |
| 6 | 7.197 | 4.883 | 6.032 |

* indicates minimum.

**Table 3.3. Lower Triangular Elements on Innovation Correlations from Corn Prices at Illinois and the Mississippi Gulf and Barge Rates with a Three-Lag VAR**

| Variables* | GF | CIL | BR |
|---|---|---|---|
| GF | 1 | | |
| CIL | 0.93 | 1 | |
| BR | 0.07 | -0.15 | 1 |

* See the definition of the variables in Table 3.1.

**Table 3.4. Forecast Error Variance Decomposition of Corn Prices at Illinois, the Mississippi Gulf and Barge Rates**

| Horizon | Std. Error | GF* | CIL | BR |
|---|---|---|---|---|
| (GF) | | | | |
| 0 | 4.74 | 100.00 | 0.00 | 0.00 |
| 1 | 7.43 | 98.23 | 1.76 | 0.01 |
| 6 | 13.77 | 78.63 | 1.00 | 20.37 |
| 12 | 17.10 | 56.66 | 1.10 | 42.24 |
| (CIL) | | | | |
| 0 | 4.53 | 86.65 | 8.78 | 4.57 |
| 1 | 7.64 | 91.29 | 5.81 | 2.90 |
| 6 | 13.99 | 80.58 | 2.39 | 17.03 |
| 12 | 17.24 | 59.10 | 1.97 | 38.93 |
| (BR) | | | | |
| 0 | 1.22 | 0.00 | 0.00 | 100.00 |
| 1 | 1.58 | 0.46 | 0.00 | 99.54 |
| 6 | 2.03 | 7.97 | 2.64 | 89.39 |
| 12 | 2.06 | 9.13 | 2.84 | 88.03 |

* See the definition of the variables in Table 3.1.

**Table 3.5. Loss Metrics on the Order of Lags (k) in a Levels Vector Autoregression on Fourteen Corn Prices, Transportation Rates, and Export Quantities**

| Lag | Schwarz-loss | Akaike's AIC | Hannan and Quinn's Φ |
|---|---|---|---|
| 0 | 14.91 | 9.69 | 12.02 |
| 1 | 12.55 * | 3.57 | 7.28 * |
| 2 | 16.77 | 3.01 * | 9.11 |
| 3 | 20.91 | 3.40 | 10.89 |

* indicates minimum.

**Table 3.6. Lower Triangular Elements on Innovation Correlations from Fourteen Corn Prices, Transportation Rates, and Export Quantities with Two-Lag VAR**

| Variable | PNW | GF | MN | SEI | CIL | MEM | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PNW | 1 | | | | | | | | | | | | | |
| GF | 0.82 | 1 | | | | | | | | | | | | |
| MN | 0.81 | 0.83 | 1 | | | | | | | | | | | |
| SEI | 0.76 | 0.86 | 0.95 | 1 | | | | | | | | | | |
| CIL | 0.81 | 0.87 | 0.93 | 0.95 | 1 | | | | | | | | | |
| MEM | 0.67 | 0.82 | 0.86 | 0.91 | 0.87 | 1 | | | | | | | | |
| BR | 0.05 | 0.12 | -0.26 | -0.20 | -0.17 | -0.07 | 1 | | | | | | | |
| RIG | 0.06 | 0.02 | 0.04 | 0.00 | 0.03 | -0.02 | 0.11 | 1 | | | | | | |
| RMP | -0.03 | -0.05 | 0.02 | 0.00 | -0.03 | 0.02 | -0.10 | 0.01 | 1 | | | | | |
| RIM | -0.01 | 0.06 | -0.01 | -0.01 | 0.00 | 0.06 | 0.07 | -0.20 | -0.02 | 1 | | | | |
| OGJ | -0.06 | -0.11 | -0.20 | -0.25 | -0.24 | -0.20 | 0.02 | 0.14 | 0.15 | -0.09 | 1 | | | |
| OPJ | -0.10 | -0.06 | -0.17 | -0.17 | -0.19 | -0.07 | 0.23 | 0.17 | 0.02 | -0.08 | 0.58 | 1 | | |
| EQG | 0.06 | 0.09 | -0.02 | 0.00 | 0.01 | 0.02 | 0.20 | -0.22 | 0.00 | -0.11 | -0.05 | -0.05 | 1 | |
| EQP | 0.24 | 0.25 | 0.21 | 0.20 | 0.25 | 0.22 | 0.15 | 0.05 | 0.08 | -0.02 | 0.08 | -0.05 | 0.17 | 1 |

* See the definition of the variables in Table 3.1.

**Table 3.7. Forecast Error Variance Decomposition of Fourteen Corn Prices, Transportation Rates, and Export Quantities with Two-Lag VAR**

| Horizon | PNW* | GF | MN | SEI | CIL | MEM | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ***(PNW)*** | | | | | | | |
| 0 | 28.06 | 5.45 | 1.47 | 63.65 | 0.98 | 0.28 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 17.59 | 4.24 | 1.49 | 64.68 | 1.59 | 0.96 | 1.36 | 0.07 | 1.84 | 0.62 | 1.13 | 3.79 | 0.21 | 0.43 |
| 12 | 7.65 | 4.10 | 3.72 | 26.04 | 1.52 | 1.51 | 16.06 | 0.28 | 6.05 | 0.40 | 25.19 | 1.65 | 0.40 | 5.44 |
| | | | | | | | ***(GF)*** | | | | | | | |
| 0 | 0.00 | 22.67 | 0.00 | 72.09 | 4.08 | 1.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 7.26 | 11.49 | 0.27 | 72.64 | 1.99 | 1.70 | 0.06 | 0.20 | 1.69 | 0.44 | 0.01 | 1.60 | 0.01 | 0.63 |
| 12 | 3.89 | 5.64 | 3.71 | 30.12 | 1.52 | 1.91 | 15.32 | 0.35 | 6.14 | 0.27 | 24.86 | 0.90 | 0.29 | 5.07 |
| | | | | | | | ***(MN)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 9.13 | 90.24 | 0.00 | 0.00 | 0.62 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 6.53 | 1.66 | 5.32 | 75.89 | 0.33 | 1.78 | 4.13 | 0.06 | 1.07 | 0.25 | 0.38 | 0.14 | 0.02 | 1.42 |
| 12 | 4.54 | 3.29 | 5.46 | 34.26 | 0.54 | 1.66 | 15.65 | 0.24 | 8.32 | 0.24 | 17.15 | 1.10 | 0.28 | 7.26 |
| | | | | | | | ***(SEI)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 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 | 5.03 | 1.44 | 0.26 | 83.47 | 0.32 | 1.74 | 3.20 | 0.18 | 1.02 | 0.29 | 0.15 | 1.60 | 0.11 | 1.18 |
| 12 | 4.44 | 3.22 | 3.98 | 35.40 | 0.78 | 1.66 | 15.38 | 0.38 | 8.16 | 0.21 | 18.72 | 1.06 | 0.44 | 6.15 |
| | | | | | | | ***(CIL)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 0.00 | 90.38 | 9.62 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 7.78 | 1.38 | 0.57 | 79.10 | 3.74 | 1.46 | 1.64 | 0.16 | 1.09 | 0.37 | 0.12 | 1.30 | 0.22 | 1.05 |
| 12 | 4.47 | 3.31 | 4.31 | 32.40 | 1.81 | 1.71 | 15.70 | 0.29 | 8.51 | 0.23 | 20.44 | 0.94 | 0.40 | 5.48 |

* See the definition of the variables in Table 3.1.

**Table 3.7. (Continued)**

| Horizon | PNW | GF | MN | SEI | CIL | MEM | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ***(MEM)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 0.00 | 82.05 | 0.00 | 17.95 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 7.53 | 3.07 | 0.01 | 64.58 | 0.06 | 15.19 | 3.43 | 0.54 | 1.57 | 0.51 | 0.38 | 0.97 | 0.38 | 1.77 |
| 12 | 3.94 | 4.35 | 4.02 | 25.87 | 1.21 | 6.13 | 17.21 | 0.51 | 6.91 | 0.32 | 21.60 | 0.87 | 0.90 | 6.16 |
| | | | | | | | ***(BR)*** | | | | | | | |
| 0 | 0.00 | 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 | 0.03 | 0.05 | 0.97 | 0.02 | 0.00 | 0.74 | 95.61 | 0.08 | 1.11 | 0.37 | 0.03 | 0.00 | 0.33 | 0.65 |
| 12 | 0.44 | 2.49 | 1.09 | 1.51 | 1.80 | 3.34 | 68.05 | 0.18 | 6.03 | 0.45 | 11.73 | 0.56 | 0.26 | 2.08 |
| | | | | | | | ***(RIG)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.25 | 88.78 | 0.00 | 5.20 | 0.00 | 0.00 | 5.76 | 0.00 |
| 1 | 1.72 | 3.94 | 0.72 | 2.78 | 0.00 | 0.17 | 0.52 | 68.93 | 4.31 | 3.89 | 3.78 | 1.94 | 7.28 | 0.00 |
| 12 | 1.67 | 6.49 | 1.09 | 2.26 | 0.76 | 0.74 | 9.49 | 51.16 | 4.07 | 3.21 | 10.95 | 1.68 | 6.10 | 0.31 |
| | | | | | | | ***(RMP)*** | | | | | | | |
| 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 | 0.00 |
| 1 | 0.82 | 0.29 | 0.10 | 1.11 | 0.02 | 1.25 | 0.41 | 0.69 | 91.28 | 0.07 | 0.36 | 0.19 | 2.82 | 0.57 |
| 12 | 0.85 | 1.19 | 2.39 | 0.82 | 1.77 | 1.41 | 7.18 | 1.29 | 61.43 | 1.11 | 16.63 | 0.37 | 2.85 | 0.68 |
| | | | | | | | ***(RIM)*** | | | | | | | |
| 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 | 0.00 |
| 1 | 2.18 | 1.30 | 1.09 | 0.13 | 0.00 | 0.04 | 0.49 | 1.56 | 0.82 | 90.30 | 0.22 | 0.40 | 0.10 | 1.34 |
| 12 | 2.82 | 1.91 | 2.15 | 1.26 | 0.85 | 0.34 | 1.72 | 1.54 | 2.69 | 77.16 | 1.63 | 1.90 | 2.54 | 1.49 |

* See the definition of the variables in Table 3.1.

**Table 3.7. (Continued)**

| Horizon | PNW | GF | MN | SEI | CIL | MEM | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ***(OGJ)*** | | | | | | | |
| 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 | 0.00 |
| 1 | 0.21 | 0.37 | 0.60 | 0.67 | 0.68 | 1.20 | 1.91 | 0.86 | 0.05 | 0.02 | 93.09 | 0.02 | 0.07 | 0.24 |
| 12 | 0.09 | 1.79 | 0.38 | 0.44 | 5.25 | 1.99 | 13.52 | 1.01 | 2.09 | 0.31 | 72.57 | 0.02 | 0.47 | 0.06 |
| | | | | | | | ***(OPJ)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.88 | 0.00 | 0.00 | 0.00 | 33.22 | 61.89 | 0.00 | 0.00 |
| 1 | 0.04 | 0.02 | 1.73 | 0.63 | 0.31 | 0.23 | 16.88 | 0.75 | 0.09 | 1.50 | 34.33 | 42.40 | 1.08 | 0.01 |
| 12 | 0.10 | 2.28 | 1.20 | 0.61 | 5.86 | 3.01 | 16.77 | 1.30 | 2.68 | 0.70 | 55.78 | 7.83 | 0.56 | 1.32 |
| | | | | | | | ***(EQG)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 95.83 | 0.00 |
| 1 | 9.73 | 1.16 | 0.01 | 1.54 | 0.50 | 1.01 | 4.71 | 0.31 | 0.61 | 2.95 | 0.28 | 0.47 | 72.43 | 4.29 |
| 12 | 10.22 | 2.50 | 0.81 | 4.02 | 1.10 | 0.93 | 12.14 | 2.66 | 5.77 | 4.32 | 2.64 | 0.36 | 48.69 | 3.83 |
| | | | | | | | ***(EQP)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.82 | 97.05 |
| 1 | 0.33 | 2.27 | 0.81 | 1.34 | 0.03 | 5.03 | 2.16 | 1.79 | 0.86 | 0.34 | 1.39 | 2.60 | 2.06 | 78.99 |
| 12 | 1.41 | 1.44 | 2.72 | 1.95 | 0.84 | 2.34 | 22.32 | 0.99 | 3.71 | 1.92 | 28.35 | 3.07 | 3.90 | 25.02 |

[*] See the definition of the variables in Table 3.1.

**Table 3.8. Augmented Dickey-Fuller Test of Non-Stationarity on Eight Grain Prices, Six Transportation Rates and Two Grain Exports**

| | Dickey-Fuller Test | | | Augmented Dickey-Fuller Test | | | |
|---|---|---|---|---|---|---|---|
| Variables* | t-stat | Q(36) | p-value | t-stat | k | Q(36) | p-value |
| PNW | -1.80 | 33.59 | 0.58 | -2.79 | 2 | 17.54 | 0.99 |
| GF | -1.71 | 59.16 | 0.01 | -2.51 | 1 | 34.05 | 0.56 |
| MN | -1.81 | 93.02 | 0.00 | -3.16 | 1 | 47.54 | 0.09 |
| SEI | -1.70 | 88.22 | 0.00 | -3.04 | 1 | 66.57 | 0.01 |
| CIL | -1.72 | 79.57 | 0.00 | -2.99 | 1 | 48.46 | 0.08 |
| MEM | -1.84 | 74.05 | 0.00 | -2.84 | 1 | 62.22 | 0.01 |
| SGF | -1.55 | 40.28 | 0.29 | -1.55 | 0 | 40.28 | 0.29 |
| SILP | -1.60 | 45.80 | 0.12 | -1.96 | 1 | 50.70 | 0.05 |
| BR | -4.95 | 132.12 | 0.00 | -4.95 | 0 | 132.12 | 0.00 |
| RIG | -6.79 | 49.55 | 0.07 | -6.79 | 0 | 49.55 | 0.07 |
| RMP | -5.57 | 57.59 | 0.01 | -5.57 | 0 | 57.59 | 0.01 |
| RIM | -8.60 | 23.43 | 0.95 | -3.41 | 7 | 18.93 | 0.99 |
| OGJ | -2.00 | 50.15 | 0.06 | -2.00 | 0 | 50.12 | 0.06 |
| OPJ | -2.01 | 42.77 | 0.20 | -2.63 | 1 | 30.65 | 0.72 |
| EQG | -4.92 | 168.78 | 0.00 | -4.92 | 0 | 168.78 | 0.00 |
| EQJ | -4.70 | 62.03 | 0.00 | -4.70 | 0 | 62.03 | 0.00 |

* See the definition of the variables in Table 3.1.

Note: The null hypothesis of Dickey-Fuller test or Augmented Dickey-Fuller test is the series is non-stationary. The test based on the estimated coefficient $\beta$ in the following model:

$$\Delta Y_t = \alpha + \beta Y_{t-1} + \sum_{k=1}^{K} \gamma_k \Delta X_{t-k}$$

The Dickey-Fuller test is a special case with K=0 in the equation. The critical value at the 5% level is -2.89. The null is rejected if the t-statistics is less than this critical value. The Q-statistic is the Lung-Box statistic on the estimated residuals from above equation. The null hypothesis is that residuals Q is white noise distributed chi-squared with 36 degree of freedom. We reject the null hypothesis for low p-values.

**Table 3.9. Loss Metrics on the Order of Lags (k) in a Levels Vector Autoregression on Eight Grain Prices, Six Transportation Rates and Two Grain Exports**

| Lag | Schwarz-loss | Akaike's AIC | Hannan and Quinn's Φ |
|---|---|---|---|
| 0 | 22.34 | 15.96 | 19.04 |
| 1 | 18.99 * | 7.77 | 12.58 * |
| 2 | 23.87 | 6.81 * | 14.35 |
| 3 | 28.95 | 7.06 | 16.33 |

* indicates minimum.

**Table 3.10. Tests of Cointegration Among Eight Grain Prices, Six Transportation Rates and Two Grain Exports**

| R | T* | C(5%)* | D* | T | C(5%) | D |
|---|---|---|---|---|---|---|
| = 0 | 1107.41 | 568.69# | Reject | 1103.80 | 550.65# | Reject |
| ≤ 1 | 933.75 | 505.44# | Reject | 930.14 | 488.88# | Reject |
| ≤ 2 | 782.49 | 446.03# | Reject | 778.91 | 430.28# | Reject |
| ≤ 3 | 660.32 | 390.01# | Reject | 656.75 | 375.18# | Reject |
| ≤ 4 | 550.76 | 338.09 | Reject | 547.37 | 323.93 | Reject |
| ≤ 5 | 453.99 | 289.70 | Reject | 450.68 | 276.37 | Reject |
| ≤ 6 | 362.69 | 244.56 | Reject | 359.39 | 232.60 | Reject |
| ≤ 7 | 293.54 | 203.34 | Reject | 290.25 | 192.30 | Reject |
| ≤ 8 | 233.61 | 165.73 | Reject | 230.42 | 155.75 | Reject |
| ≤ 9 | 178.71 | 132.00 | Reject | 175.56 | 123.04 | Reject |
| ≤ 10 | 128.74 | 101.84 | Reject | 125.70 | 63.92 | Reject |
| ≤ 11 | 89.71 | 75.74 | Reject | 86.73 | 68.68 | Reject |
| ≤ 12 | 52.64 | 53.42 | F.T.R + | 50.47 | 47.21 | Reject |
| ≤ 13 | 30.64 | 34.79 | F.T.R | 28.51 | 29.38 | F.T.R |
| ≤ 14 | 12.89 | 19.99 | F.T.R | 10.81 | 15.34 | F.T.R |
| ≤ 15 | 3.42 | 9.13 | F.T.R | 1.89 | 3.884 | F.T.R |

# Episodes identified by the author.

Notes: The number of cointegrating vectors (R) is tested using the trace test with the constant within and outside the cointegrating vectors. The test statistic (T) is the calculated trace test, associated with the number of cointegrating vectors given in the left-hand-most most column. The critical values (C(5%)) are taken from Table B.2 (within) and Table B.3 (outside) in Hansen and Juselius (p.80-81) except for R equals 0 through 3 that are episodes identified by the author. 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 or fail to reject (F.T.R), at a 5 percent level of significance, the null hypothesis of the number of cointegrating vectors (R=0, R≤ 1,…, R≤ 15). Following Johansen (1992), the author stop testing at the first "F.T.R" 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.

**Table 3.11. Tests of Exclusion on Sixteen Series from the Cointegration Space**

| Variables* | Chi-Squared Test | p-value | Decision |
|---|---|---|---|
| PNW | 83.79 | .00 | Reject |
| GF | 80.15 | .00 | Reject |
| MN | 56.83 | .00 | Reject |
| SEI | 96.57 | .00 | Reject |
| CIL | 62.52 | .00 | Reject |
| MEM | 73.00 | .00 | Reject |
| SGF | 68.03 | .00 | Reject |
| SILP | 63.05 | .00 | Reject |
| BR | 95.26 | .00 | Reject |
| RIG | 81.41 | .00 | Reject |
| RMP | 50.60 | .00 | Reject |
| RIM | 84.14 | .00 | Reject |
| OGJ | 64.25 | .00 | Reject |
| OPJ | 52.66 | .00 | Reject |
| EQG | 72.81 | .00 | Reject |
| EQJ | 54.13 | .00 | Reject |

* See the definition of the variables in Table 3.1.

Notes: Tests are on the null hypothesis that the particular series is not in the cointegration space. Decision to reject or fail to reject the null hypothesis is at a 5 percent level of significance. Under the null hypothesis, the test statistic is distributed chi-squared with twelve degrees of freedom.

**Table 3.12. Tests of Weak Exogeneity on Sixteen Series for Grain Market Channel**

| Variables* | Chi-Squared Test | p-value | Decision |
|---|---|---|---|
| PNW | 68.69 | .00 | Reject |
| GF | 74.94 | .00 | Reject |
| MN | 88.33 | .00 | Reject |
| SEI | 85.08 | .00 | Reject |
| CIL | 80.10 | .00 | Reject |
| MEM | 71.26 | .00 | Reject |
| SGF | 40.65 | .00 | Reject |
| SILP | 45.33 | .00 | Reject |
| BR | 44.86 | .00 | Reject |
| RIG | 69.21 | .00 | Reject |
| RMP | 31.98 | .00 | Reject |
| RIM | 65.72 | .00 | Reject |
| OGJ | 14.25 | .30 | F.T.R. |
| OPJ | 37.41 | .00 | Reject |
| EQG | 41.30 | .00 | Reject |
| EQJ | 34.56 | .00 | Reject |

* See the definition of the variables in Table 3.1.

Notes: Tests are on the null hypothesis that the particular series does not respond to perturbations in the cointegrating space. Decision to reject or fail to reject (F.T.R) the null hypothesis is at a 5 percent level of significance. Under the null hypothesis, the test statistic is distributed chi-squared with twelve degrees of freedom.

**Table 3.13. Lower Triangular Elements on Innovation Covariance from Six Corn Prices, Two Soybean Prices, Six Transportation Rates, and Two Export Quantities with a Two-Lag ECM**

| | PNW* | GF | MN | SEI | CIL | MEM | SGF | SILP | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQJ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PNW | 15.17 | | | | | | | | | | | | | | | |
| GF | 9.24 | 8.57 | | | | | | | | | | | | | | |
| MN | 9.21 | 7.54 | 9.37 | | | | | | | | | | | | | |
| SEI | 8.07 | 7.12 | 8.24 | 7.96 | | | | | | | | | | | | |
| CIL | 8.64 | 7.10 | 8.04 | 7.55 | 8.02 | | | | | | | | | | | |
| MEM | 7.07 | 6.55 | 7.44 | 7.13 | 6.86 | 7.66 | | | | | | | | | | |
| SGF | 6.91 | 7.82 | 8.42 | 9.17 | 8.54 | 9.50 | 33.58 | | | | | | | | | |
| SILP | 6.29 | 6.74 | 8.49 | 9.14 | 8.63 | 9.21 | 31.91 | 32.88 | | | | | | | | |
| BR | 0.54 | 0.34 | -0.70 | -0.57 | -0.48 | -0.33 | 0.15 | -0.53 | 0.97 | | | | | | | |
| RIG | -0.25 | -0.20 | -0.26 | -0.26 | -0.19 | -0.17 | 0.22 | 0.16 | 0.22 | 0.98 | | | | | | |
| RMP | -0.10 | -0.11 | 0.07 | 0.05 | -0.06 | 0.24 | -0.29 | -0.18 | -0.04 | 0.03 | 1.50 | | | | | |
| RIM | 0.02 | 0.06 | 0.02 | -0.01 | -0.02 | 0.05 | -0.28 | -0.37 | 0.01 | -0.08 | 0.00 | 0.27 | | | | |
| OGJ | -0.46 | -0.39 | -0.89 | -0.90 | -0.88 | -0.59 | -1.74 | -2.14 | 0.12 | 0.13 | 0.19 | -0.04 | 1.36 | | | |
| OPJ | -0.31 | -0.18 | -0.38 | -0.35 | -0.39 | -0.16 | -0.65 | -0.82 | 0.17 | 0.13 | 0.02 | -0.04 | 0.45 | 0.40 | | |
| EQG | 0.05 | 0.06 | 0.06 | 0.01 | 0.03 | 0.04 | -0.31 | -0.31 | 0.04 | -0.08 | -0.01 | -0.05 | -0.06 | -0.04 | 0.26 | |
| EQJ | 0.15 | 0.09 | 0.10 | 0.06 | 0.10 | 0.07 | 0.00 | -0.02 | 0.03 | 0.02 | 0.01 | -0.01 | 0.01 | -0.01 | 0.03 | 0.04 |

[*] See the definition of the variables in Table 3.1.

**Table 3.14. Lower Triangular Elements on Innovation Covariance from Six Corn Prices, Two Soybean Prices, Six Transportation Rates, and Two Export Quantities with a Two-Lag VAR**

| | PNW* | GF | MN | SEI | CIL | MEM | SGF | SILP | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQJ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PNW | 15.44 | | | | | | | | | | | | | | | |
| GF | 9.42 | 8.75 | | | | | | | | | | | | | | |
| MN | 9.30 | 7.64 | 9.45 | | | | | | | | | | | | | |
| SEI | 8.12 | 7.21 | 8.27 | 8.02 | | | | | | | | | | | | |
| CIL | 8.74 | 7.26 | 8.15 | 7.59 | 8.13 | | | | | | | | | | | |
| MEM | 7.11 | 6.67 | 7.53 | 7.18 | 6.99 | 7.75 | | | | | | | | | | |
| SGF | 6.86 | 7.75 | 8.41 | 9.23 | 8.47 | 9.56 | 33.88 | | | | | | | | | |
| SILP | 6.12 | 6.49 | 8.52 | 9.16 | 8.56 | 9.16 | 32.26 | 33.33 | | | | | | | | |
| BR | 0.59 | 0.38 | -0.71 | -0.57 | -0.48 | -0.33 | 0.06 | -0.58 | 1.00 | | | | | | | |
| RIG | -0.23 | -0.18 | -0.24 | -0.25 | -0.20 | -0.17 | 0.17 | 0.11 | 0.22 | 0.99 | | | | | | |
| RMP | -0.05 | -0.07 | 0.11 | 0.07 | -0.04 | 0.27 | -0.36 | -0.21 | -0.02 | 0.04 | 1.51 | | | | | |
| RIM | 0.04 | 0.06 | 0.02 | -0.01 | -0.02 | 0.04 | -0.31 | -0.36 | 0.02 | -0.08 | 0.00 | 0.28 | | | | |
| OGJ | -0.52 | -0.39 | -0.92 | -0.91 | -0.89 | -0.60 | -1.74 | -2.21 | 0.12 | 0.13 | 0.19 | -0.04 | 1.43 | | | |
| OPJ | -0.38 | -0.19 | -0.42 | -0.37 | -0.41 | -0.16 | -0.64 | -0.82 | 0.16 | 0.13 | 0.01 | -0.04 | 0.47 | 0.42 | | |
| EQG | 0.08 | 0.08 | 0.08 | 0.01 | 0.03 | 0.04 | -0.30 | -0.30 | 0.05 | -0.08 | -0.01 | -0.05 | -0.06 | -0.04 | 0.26 | |
| EQJ | 0.18 | 0.11 | 0.11 | 0.07 | 0.11 | 0.08 | -0.01 | -0.02 | 0.04 | 0.02 | 0.02 | -0.01 | 0.01 | -0.02 | 0.03 | 0.05 |

[*] See the definition of the variables in Table 3.1.

**Table 3.15. Lower Triangular Elements on Weighted Average Innovation Covariance from Tables 3.13 and 3.14**

| | PNW* | GF | MN | SEI | CIL | MEM | SGF | SILP | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQJ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PNW | 15.30 | | | | | | | | | | | | | | | |
| GF | 9.33 | 8.66 | | | | | | | | | | | | | | |
| MN | 9.26 | 7.59 | 9.41 | | | | | | | | | | | | | |
| SEI | 8.10 | 7.17 | 8.25 | 7.99 | | | | | | | | | | | | |
| CIL | 8.69 | 7.18 | 8.09 | 7.57 | 8.08 | | | | | | | | | | | |
| MEM | 7.09 | 6.61 | 7.48 | 7.15 | 6.93 | 7.71 | | | | | | | | | | |
| SGF | 6.89 | 7.79 | 8.42 | 9.20 | 8.51 | 9.53 | 33.73 | | | | | | | | | |
| SILP | 6.21 | 6.62 | 8.50 | 9.15 | 8.60 | 9.18 | 32.09 | 33.10 | | | | | | | | |
| BR | 0.57 | 0.36 | -0.71 | -0.57 | -0.48 | -0.33 | 0.11 | -0.55 | 0.99 | | | | | | | |
| RIG | -0.24 | -0.19 | -0.25 | -0.26 | -0.20 | -0.17 | 0.19 | 0.13 | 0.22 | 0.98 | | | | | | |
| RMP | -0.07 | -0.09 | 0.09 | 0.06 | -0.05 | 0.25 | -0.33 | -0.20 | -0.03 | 0.04 | 1.50 | | | | | |
| RIM | 0.03 | 0.06 | 0.02 | -0.01 | -0.02 | 0.04 | -0.30 | -0.36 | 0.02 | -0.08 | 0.00 | 0.28 | | | | |
| OGJ | -0.49 | -0.39 | -0.90 | -0.90 | -0.88 | -0.60 | -1.74 | -2.18 | 0.12 | 0.13 | 0.19 | -0.04 | 1.40 | | | |
| OPJ | -0.35 | -0.18 | -0.40 | -0.36 | -0.40 | -0.16 | -0.64 | -0.82 | 0.16 | 0.13 | 0.01 | -0.04 | 0.46 | 0.41 | | |
| EQG | 0.06 | 0.07 | 0.07 | 0.01 | 0.03 | 0.04 | -0.31 | -0.30 | 0.04 | -0.08 | -0.01 | -0.05 | -0.06 | -0.04 | 0.26 | |
| EQJ | 0.16 | 0.10 | 0.11 | 0.07 | 0.10 | 0.07 | 0.00 | -0.02 | 0.04 | 0.02 | 0.02 | -0.01 | 0.01 | -0.01 | 0.03 | 0.04 |

* See the definition of the variables in Table 3.1.

**Table 3.16. Forecast Error Variance Decomposition of Six Corn Prices, Two Soybean Prices, Six Transportation Rates, and Two Export Quantities with a Two-Lag ECM**

| Horizon | PNW | GF | MN | SEI | CIL | MEM | SGF | SILP | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | ***(PNW)**** | | | | | | | | |
| 0 | 34.39 | 17.08 | 43.79 | 4.73 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 17.68 | 16.49 | 40.59 | 3.83 | 0.00 | 1.04 | 0.20 | 5.06 | 4.07 | 0.05 | 1.50 | 0.07 | 2.02 | 3.13 | 0.31 | 3.95 |
| 12 | 5.80 | 6.73 | 15.72 | 4.57 | 0.61 | 1.22 | 1.62 | 9.05 | 1.91 | 1.29 | 4.53 | 0.65 | 10.81 | 12.20 | 6.74 | 16.55 |
| | | | | | | | | ***(GF)*** | | | | | | | | |
| 0 | 0.00 | 26.04 | 66.75 | 7.21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 0.52 | 10.84 | 58.33 | 8.23 | 0.04 | 0.53 | 0.03 | 9.87 | 0.12 | 0.08 | 2.34 | 0.39 | 0.00 | 1.67 | 0.38 | 1.96 |
| 12 | 1.57 | 3.70 | 22.59 | 5.04 | 0.86 | 1.22 | 0.42 | 18.43 | 0.21 | 0.86 | 6.31 | 0.28 | 7.24 | 11.20 | 4.67 | 15.39 |
| | | | | | | | | ***(MN)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 100.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.21 | 0.00 | 0.16 |
| 1 | 2.34 | 0.05 | 83.43 | 3.13 | 0.50 | 1.35 | 0.04 | 2.88 | 0.60 | 0.07 | 1.01 | 0.02 | 0.16 | 2.45 | 0.34 | 1.92 |
| 12 | 0.86 | 0.29 | 28.02 | 2.76 | 0.77 | 2.70 | 3.66 | 16.68 | 3.40 | 2.07 | 4.74 | 0.21 | 2.68 | 11.87 | 7.58 | 11.70 |
| | | | | | | | | ***(SEI)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 90.25 | 9.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 2.90 | 0.30 | 76.84 | 9.86 | 0.47 | 1.21 | 0.02 | 2.95 | 0.87 | 0.02 | 1.23 | 0.11 | 0.14 | 2.41 | 0.02 | 0.84 |
| 12 | 1.18 | 0.54 | 28.91 | 5.23 | 0.93 | 2.03 | 2.16 | 17.35 | 2.13 | 1.68 | 5.95 | 0.23 | 3.83 | 10.51 | 6.06 | 11.28 |
| | | | | | | | | ***(CIL)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 86.27 | 3.47 | 10.04 | 0.21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 4.50 | 0.24 | 74.77 | 5.18 | 3.99 | 1.31 | 0.03 | 5.07 | 0.25 | 0.02 | 1.22 | 0.18 | 0.14 | 2.07 | 0.02 | 0.99 |
| 12 | 1.37 | 0.79 | 26.65 | 4.50 | 1.74 | 2.02 | 1.71 | 18.76 | 1.45 | 0.99 | 6.60 | 0.34 | 4.58 | 10.67 | 5.69 | 12.11 |
| | | | | | | | | ***(MEM)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 74.74 | 8.07 | 0.00 | 17.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 6.29 | 1.97 | 57.17 | 10.20 | 0.37 | 11.92 | 0.03 | 3.85 | 1.55 | 0.47 | 2.01 | 0.52 | 0.43 | 1.70 | 0.06 | 1.44 |
| 12 | 1.95 | 1.23 | 22.31 | 4.91 | 1.75 | 4.70 | 0.63 | 25.06 | 1.61 | 0.39 | 6.32 | 0.39 | 4.79 | 9.51 | 4.29 | 10.14 |

* See the definition of the variables in Table 3.1.

**Table 3.16. (Continued)**

| Horizon | PNW | GF | MN | SEI | CIL | MEM | SGF | SILP | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | ***(SGF)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 26.01 | 2.81 | 0.00 | 5.98 | 65.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 2.94 | 0.36 | 15.70 | 4.18 | 0.07 | 9.21 | 58.86 | 3.95 | 1.92 | 0.05 | 1.84 | 0.00 | 0.31 | 0.13 | 0.48 | 0.00 |
| 12 | 3.89 | 1.33 | 5.31 | 1.69 | 2.33 | 2.91 | 31.15 | 1.22 | 9.68 | 5.99 | 1.27 | 0.72 | 13.90 | 1.89 | 14.81 | 1.92 |
| | | | | | | | | | ***(SILP)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 23.97 | 2.59 | 0.00 | 5.51 | 60.08 | 7.84 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 2.39 | 0.50 | 15.61 | 3.33 | 0.42 | 9.14 | 61.25 | 3.00 | 1.65 | 0.00 | 1.57 | 0.02 | 0.43 | 0.14 | 0.50 | 0.03 |
| 12 | 4.82 | 1.33 | 4.14 | 1.31 | 3.47 | 2.35 | 34.62 | 0.98 | 7.50 | 7.09 | 1.58 | 1.25 | 12.02 | 1.48 | 14.15 | 1.90 |
| | | | | | | | | | ***(BR)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 5.83 | 0.00 | 0.00 | 0.01 | 0.08 | 0.00 | 82.69 | 0.00 | 0.00 | 0.00 | 1.74 | 3.14 | 0.00 | 6.51 |
| 1 | 3.65 | 4.67 | 6.35 | 1.42 | 0.01 | 1.93 | 0.89 | 0.74 | 64.33 | 1.45 | 3.48 | 1.26 | 1.03 | 2.74 | 0.20 | 5.84 |
| 12 | 1.14 | 1.42 | 9.69 | 0.35 | 1.05 | 4.55 | 9.14 | 15.03 | 37.63 | 1.36 | 0.77 | 1.64 | 8.84 | 0.63 | 2.52 | 4.25 |
| | | | | | | | | | ***(RIG)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.71 | 91.71 | 0.00 | 0.00 | 0.10 | 0.18 | 2.96 | 0.00 |
| 1 | 0.11 | 1.05 | 6.32 | 0.89 | 0.14 | 0.15 | 0.29 | 1.05 | 4.01 | 73.22 | 4.11 | 1.12 | 2.86 | 1.62 | 2.71 | 0.35 |
| 12 | 1.30 | 8.83 | 5.69 | 1.16 | 1.68 | 0.73 | 1.67 | 3.73 | 9.90 | 44.72 | 2.73 | 2.19 | 8.14 | 1.54 | 1.88 | 4.09 |
| | | | | | | | | | ***(RMP)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 0.27 | 0.00 | 0.00 | 0.01 | 0.07 | 0.00 | 0.00 | 0.00 | 98.31 | 0.00 | 1.58 | 0.00 | 0.00 | 0.00 |
| 1 | 0.75 | 0.07 | 0.09 | 0.01 | 0.11 | 1.32 | 0.06 | 0.13 | 3.13 | 0.84 | 89.02 | 0.06 | 3.99 | 0.17 | 0.08 | 0.17 |
| 12 | 1.08 | 4.65 | 0.67 | 2.60 | 0.43 | 1.22 | 0.74 | 2.61 | 4.11 | 1.16 | 55.85 | 0.35 | 19.50 | 1.44 | 1.68 | 1.90 |
| | | | | | | | | | ***(RIM)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.16 | 3.15 | 0.00 | 93.06 | 0.00 | 0.01 | 3.13 | 0.47 |
| 1 | 8.16 | 1.55 | 0.29 | 0.14 | 0.52 | 1.10 | 0.52 | 0.97 | 0.27 | 3.44 | 0.29 | 75.52 | 0.01 | 0.54 | 3.26 | 2.14 |
| 12 | 6.37 | 2.13 | 2.12 | 1.78 | 1.21 | 2.05 | 4.24 | 1.62 | 4.77 | 4.05 | 1.19 | 56.46 | 0.65 | 1.97 | 7.40 | 1.98 |

**Table 3.16. (Continued)**

| Horizon | PNW | GF | MN | SEI | CIL | MEM | SGF | SILP | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | ***(OGJ)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 1.62 | 0.17 | 0.00 | 0.37 | 4.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 93.75 | 0.00 | 0.00 | 0.00 |
| 1 | 0.00 | 0.68 | 5.47 | 0.07 | 1.24 | 1.03 | 3.34 | 0.01 | 1.45 | 0.30 | 0.00 | 0.32 | 85.84 | 0.14 | 0.00 | 0.08 |
| 12 | 0.06 | 0.32 | 3.73 | 2.14 | 1.55 | 0.86 | 4.92 | 1.29 | 2.12 | 1.03 | 0.64 | 0.36 | 79.37 | 0.15 | 1.02 | 0.43 |
| | | | | | | | | ***(OPJ)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 0.60 | 0.06 | 0.00 | 0.14 | 1.52 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 34.88 | 62.79 | 0.00 | 0.00 |
| 1 | 0.01 | 0.29 | 6.10 | 0.19 | 0.22 | 0.82 | 2.60 | 0.30 | 5.07 | 1.16 | 0.21 | 1.01 | 36.45 | 45.40 | 0.15 | 0.00 |
| 12 | 0.22 | 0.13 | 9.38 | 1.14 | 0.90 | 3.44 | 12.40 | 0.41 | 5.47 | 4.00 | 1.81 | 0.33 | 42.29 | 13.08 | 1.81 | 3.18 |
| | | | | | | | | ***(EQG)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 90.39 | 9.61 |
| 1 | 0.82 | 0.63 | 0.01 | 0.23 | 0.04 | 0.07 | 4.07 | 5.92 | 0.07 | 0.38 | 0.70 | 5.82 | 0.06 | 0.45 | 70.25 | 10.46 |
| 12 | 4.29 | 1.85 | 0.88 | 0.72 | 2.38 | 1.05 | 13.39 | 7.52 | 4.25 | 1.41 | 2.68 | 3.04 | 2.97 | 7.54 | 34.69 | 11.32 |
| | | | | | | | | ***(EQP)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 |
| 1 | 0.22 | 1.01 | 2.93 | 0.08 | 0.16 | 1.83 | 0.45 | 1.10 | 1.60 | 1.32 | 0.41 | 0.14 | 1.37 | 3.72 | 0.00 | 83.65 |
| 12 | 0.36 | 2.17 | 1.80 | 0.28 | 0.11 | 0.57 | 2.84 | 1.07 | 9.66 | 0.62 | 2.18 | 1.53 | 11.65 | 18.72 | 1.72 | 44.69 |

**Table 3.17. Forecast Error Variance Decomposition of Six Corn Prices, Two Soybean Prices, Six Transportation Rates, and Two Export Quantities with a Two-Lag VAR**

| Horizon | PNW | GF | MN | SEI | CIL | MEM | SGF | SILP | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***(PNW)***[*] | | | | | | | | | | | | | | | | |
| 0 | 34.31 | 16.82 | 44.44 | 4.42 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.10 | 0.00 | 0.12 |
| 1 | 17.77 | 17.03 | 41.95 | 3.80 | 0.00 | 1.00 | 0.20 | 5.08 | 3.77 | 0.05 | 1.34 | 0.08 | 2.52 | 2.32 | 0.34 | 2.76 |
| 12 | 7.60 | 8.15 | 19.02 | 6.80 | 1.65 | 1.09 | 1.47 | 5.72 | 5.35 | 0.52 | 3.66 | 0.85 | 27.28 | 1.47 | 2.11 | 7.25 |
| ***(GF)*** | | | | | | | | | | | | | | | | |
| 0 | 0.00 | 25.61 | 67.66 | 6.73 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 5.33 | 10.89 | 60.16 | 8.03 | 0.05 | 0.47 | 0.02 | 9.08 | 0.19 | 0.09 | 2.06 | 0.32 | 0.00 | 1.34 | 0.42 | 1.55 |
| 12 | 2.21 | 3.99 | 26.57 | 7.92 | 1.43 | 1.00 | 1.00 | 8.91 | 3.97 | 0.71 | 4.39 | 0.59 | 27.82 | 0.97 | 1.38 | 7.15 |
| ***(MN)*** | | | | | | | | | | | | | | | | |
| 0 | 0.00 | 0.00 | 100.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 2.56 | 0.06 | 84.43 | 2.91 | 0.53 | 1.27 | 0.03 | 2.62 | 0.55 | 0.06 | 0.91 | 0.01 | 0.11 | 1.92 | 0.32 | 1.69 |
| 12 | 1.96 | 0.36 | 35.88 | 6.11 | 1.36 | 1.11 | 3.41 | 8.61 | 2.57 | 1.29 | 4.49 | 0.57 | 18.64 | 1.80 | 3.47 | 8.36 |
| ***(SEI)*** | | | | | | | | | | | | | | | | |
| 0 | 0.00 | 0.00 | 90.95 | 9.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 2.86 | 0.33 | 78.08 | 9.20 | 0.49 | 1.17 | 0.03 | 2.61 | 0.77 | 0.03 | 1.15 | 0.08 | 0.10 | 2.28 | 0.01 | 0.79 |
| 12 | 2.21 | 0.58 | 34.09 | 8.74 | 1.48 | 0.94 | 2.43 | 8.28 | 2.63 | 1.18 | 5.18 | 0.53 | 20.67 | 1.62 | 2.45 | 6.97 |
| ***(CIL)*** | | | | | | | | | | | | | | | | |
| 0 | 0.00 | 0.00 | 85.86 | 4.09 | 9.97 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 4.80 | 0.25 | 75.61 | 5.47 | 4.02 | 1.09 | 0.04 | 4.55 | 0.20 | 0.02 | 1.05 | 0.13 | 0.08 | 1.83 | 0.02 | 0.82 |
| 12 | 2.42 | 0.75 | 31.03 | 8.03 | 2.55 | 1.03 | 2.23 | 8.98 | 2.78 | 0.51 | 5.47 | 0.72 | 23.20 | 1.38 | 2.14 | 6.77 |
| ***(MEM)*** | | | | | | | | | | | | | | | | |
| 0 | 0.00 | 0.00 | 75.69 | 7.53 | 0.00 | 16.78 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 6.88 | 2.07 | 58.18 | 9.65 | 0.43 | 11.80 | 0.02 | 3.19 | 1.29 | 0.52 | 1.89 | 0.42 | 0.43 | 1.65 | 0.07 | 1.49 |
| 12 | 2.71 | 1.26 | 26.70 | 8.17 | 1.90 | 4.68 | 1.22 | 9.64 | 3.71 | 0.39 | 5.06 | 0.61 | 24.10 | 1.61 | 1.62 | 6.61 |

[*] See the definition of the variables in Table 3.1.

**Table 3.17. (Continued)**

| Horizon | PNW | GF | MN | SEI | CIL | MEM | SGF | SILP | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | ***(SGF)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 26.55 | 2.64 | 0.00 | 5.88 | 64.93 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 3.41 | 0.19 | 15.86 | 3.96 | 0.07 | 9.00 | 58.96 | 3.75 | 1.77 | 0.07 | 1.92 | 0.00 | 0.39 | 0.18 | 0.42 | 0.01 |
| 12 | 5.39 | 1.09 | 4.67 | 2.15 | 2.88 | 2.95 | 31.10 | 2.89 | 4.15 | 4.74 | 1.22 | 1.01 | 16.41 | 1.60 | 12.09 | 5.65 |
| | | | | | | | | ***(SILP)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 24.49 | 2.44 | 0.00 | 5.43 | 59.89 | 7.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 2.68 | 0.30 | 15.91 | 3.06 | 0.40 | 9.12 | 60.70 | 3.11 | 1.76 | 0.00 | 1.73 | 0.01 | 0.49 | 0.19 | 0.43 | 0.07 |
| 12 | 5.88 | 0.93 | 4.50 | 1.83 | 3.05 | 2.85 | 33.89 | 2.49 | 4.44 | 5.45 | 1.26 | 1.06 | 13.13 | 1.76 | 12.28 | 5.18 |
| | | | | | | | | ***(BR)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 5.64 | 0.00 | 0.00 | 0.01 | 0.09 | 0.00 | 83.78 | 0.00 | 0.00 | 0.00 | 2.01 | 3.75 | 0.00 | 4.71 |
| 1 | 2.66 | 3.53 | 5.74 | 1.51 | 0.03 | 1.81 | 0.89 | 1.00 | 66.94 | 1.44 | 3.57 | 1.48 | 1.28 | 3.81 | 0.32 | 3.97 |
| 12 | 1.49 | 1.18 | 8.51 | 0.48 | 0.76 | 5.52 | 12.76 | 9.13 | 34.68 | 1.81 | 1.79 | 0.85 | 11.75 | 3.96 | 3.23 | 2.10 |
| | | | | | | | | ***(RIG)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 0.31 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.68 | 91.85 | 0.00 | 0.00 | 0.11 | 0.21 | 2.83 | 0.00 |
| 1 | 0.15 | 0.86 | 5.57 | 0.69 | 0.18 | 0.18 | 0.33 | 0.96 | 4.10 | 74.73 | 3.79 | 1.22 | 2.64 | 1.68 | 2.55 | 0.34 |
| 12 | 1.52 | 8.15 | 5.18 | 1.00 | 2.20 | 0.92 | 1.80 | 3.34 | 6.36 | 49.07 | 2.87 | 2.05 | 10.33 | 2.35 | 1.88 | 1.07 |
| | | | | | | | | ***(RMP)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.01 | 0.07 | 0.00 | 0.00 | 0.00 | 98.29 | 0.00 | 1.59 | 0.00 | 0.00 | 0.00 |
| 1 | 0.63 | 0.20 | 0.13 | 0.01 | 0.08 | 1.30 | 0.06 | 0.20 | 3.10 | 0.84 | 88.71 | 0.08 | 4.22 | 0.33 | 0.07 | 0.02 |
| 12 | 1.14 | 5.01 | 1.93 | 2.33 | 0.98 | 1.60 | 0.75 | 2.26 | 5.06 | 1.19 | 57.01 | 0.56 | 18.36 | 0.30 | 0.99 | 0.50 |
| | | | | | | | | ***(RIM)*** | | | | | | | | |
| 0 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.16 | 3.16 | 0.00 | 92.89 | 0.00 | 0.01 | 3.33 | 0.44 |
| 1 | 6.75 | 1.27 | 0.13 | 1.44 | 0.43 | 0.11 | 0.52 | 1.10 | 0.17 | 3.38 | 0.38 | 76.82 | 0.01 | 0.29 | 3.45 | 2.73 |
| 12 | 5.62 | 1.63 | 1.13 | 2.29 | 1.29 | 1.76 | 2.13 | 2.07 | 1.38 | 3.74 | 1.39 | 62.72 | 0.82 | 2.82 | 6.71 | 2.50 |

**Table 3.17. (Continued)**

| Horizon | PNW | GF | MN | SEI | CIL | MEM | SGF | SILP | BR | RIG | RMP | RIM | OGJ | OPJ | EQG | EQP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | ***(OGJ)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 1.75 | 0.17 | 0.00 | 0.39 | 4.29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 93.39 | 0.00 | 0.00 | 0.00 |
| 1 | 0.00 | 0.71 | 6.41 | 0.08 | 1.28 | 1.20 | 3.38 | 0.04 | 2.02 | 0.32 | 0.00 | 0.38 | 83.86 | 0.16 | 0.01 | 0.15 |
| 12 | 0.05 | 0.44 | 7.48 | 0.51 | 3.28 | 2.38 | 3.05 | 4.83 | 7.51 | 0.61 | 1.37 | 1.19 | 65.22 | 0.30 | 0.88 | 0.88 |
| | | | | | | | | | ***(OPJ)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 0.64 | 0.06 | 0.00 | 0.14 | 1.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 33.98 | 63.62 | 0.00 | 0.00 |
| 1 | 0.06 | 0.13 | 5.33 | 0.21 | 0.17 | 0.79 | 1.95 | 0.14 | 6.58 | 1.26 | 0.19 | 0.97 | 35.88 | 46.15 | 0.13 | 0.04 |
| 12 | 0.17 | 0.28 | 9.12 | 0.44 | 3.61 | 3.13 | 3.24 | 6.34 | 9.34 | 1.64 | 1.86 | 0.97 | 49.48 | 9.90 | 0.24 | 0.23 |
| | | | | | | | | | ***(EQG)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 91.20 | 8.80 |
| 1 | 0.95 | 0.61 | 0.17 | 0.32 | 0.04 | 0.06 | 3.14 | 4.81 | 0.03 | 0.56 | 0.65 | 6.07 | 0.10 | 0.21 | 73.05 | 9.24 |
| 12 | 4.32 | 1.39 | 1.00 | 0.68 | 0.85 | 2.10 | 15.10 | 3.95 | 7.47 | 2.19 | 0.62 | 3.81 | 3.83 | 0.88 | 44.92 | 6.89 |
| | | | | | | | | | ***(EQP)*** | | | | | | | |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 |
| 1 | 0.37 | 1.37 | 1.46 | 0.28 | 0.34 | 1.30 | 0.47 | 1.07 | 1.17 | 1.61 | 0.26 | 0.19 | 2.41 | 2.07 | 0.02 | 85.61 |
| 12 | 0.62 | 0.91 | 5.40 | 0.75 | 0.47 | 2.97 | 9.80 | 3.04 | 15.00 | 1.34 | 0.45 | 0.57 | 28.43 | 2.41 | 0.60 | 27.23 |

**Table 3.18. Comparison of Long-run Influence of Transportation Rates on Grain Prices from Four Models**

| | Simplified-Corn | Extended-Corn | Corn-Soybeans | Corn-Soybeans |
|---|---|---|---|---|
| | VAR | VAR | VAR | ECM |
| Export Corn Markets | | | | |
| Barge | 42.2 | 15.3-16.1 | 4.0-5.3 | 0.2-1.9 |
| Railroad | NA* | 6.7-7.0 | 5.0-5.7 | 6.5-7.4 |
| Ocean | NA | 25.8-26.8 | ~28.8 | 18.4-23.0 |
| Total | 42.2 | 47.8-49.9 | 37.8-39.8 | 25.1-32.3 |
| Domestic Corn Markets | | | | |
| Barge | 38.9 | 15.4-17.2 | 2.6-3.7 | 1.4-3.4 |
| Railroad | NA | 7.7-9.0 | 6.1-6.9 | 7.0-7.9 |
| Ocean | NA | 18.2-22.5 | 20.4-25.7 | 14.3-15.2 |
| Total | 38.9 | 41.3-48.7 | 29.1-36.3 | 22.7-26.5 |
| Export Soybean Markets | | | | |
| Barge | NA | NA | 4.1 | 9.7 |
| Railroad | NA | NA | 7.0 | 8.0 |
| Ocean | NA | NA | 18.0 | 15.8 |
| Total | NA | NA | 29.1 | 33.5 |
| Domestic Soybean Markets | | | | |
| Barge | NA | NA | 4.4 | 7.5 |
| Railroad | NA | NA | 7.8 | 8.0 |
| Ocean | NA | NA | 14.9 | 13.5 |
| Total | NA | NA | 27.1 | 29 |

* Indicates not applicable.

**Table 4.1. Definition of Variables in Grain Barge Demand Equations for Upper Mississippi and Illinois Rivers**

| Variables | Definitions |
|---|---|
| ***Mississippi River*** | |
| $BQUM_i$ | Quantity of grain entering upper Mississippi River from Iowa and Minnesota in month *i* |
| $BRNI_i$ | North Iowa grain barge rate in month *i* |
| $GSTOCKUM_i$ | Quantity of grain stocks at Minnesota and Iowa in month *i* |
| $TCDOM_i$ | Total domestic corn consumptions in month *i* |
| $OCEANS_i$ | Spread of ocean freight rates between Mississippi Gulf and Pacific Northwest to Japan in month *i* |
| $RRMR_i$ | Rail rate for Minnesota-originated grain to upper Mississippi River elevators in month *i* |
| $RRPNW_i$ | Rail rate for grain to Pacific Northwest ports in month *i* |
| CLOSURE | Dummy variable for river closure: December, January, February = 1; others = 0. |
| FLOOD | Dummy variable for river closure caused by flood: flood = 1; no-flood = 0. |
| ***Illinois River*** | |
| $BQIL_i$ | Quantity of grain entering Illinois River from Illinois in month *i* |
| $BRSP_i$ | South of Peoria grain barge rate in month *i* |
| $CNILP_i$ | Central Illinois corn price in month *i* |
| $GSTOCKIL_i$ | Quantity of grain stocks in Illinois in month *i* |
| $RRGF_i$ | Rail rate for grain shipped from Illinois to Mississippi Gulf in month *i* |
| $OCEAN_i$ | Ocean freight rate from Mississippi Gulf to Japan in month *i* |
| WINTER | Dummy variable for winter quarter: January, February, March = 1; others = 0. |
| ***For Both Rivers*** | |
| $GEXPQ_i$ | Quantity of grain exported at Mississippi Gulf ports in month *i* |

**Table 4.2. Statistical Summary of Variables Included in Grain Barge Demand Equations**

| Variables* | Unit | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| ***Mississippi River*** | | | | | |
| BQUM | 1,000 tons | 1,738.65 | 1,057.13 | 1.85 | 3,504.92 |
| BRNI | $ / ton | 10.40 | 3.33 | 5.51 | 19.26 |
| GSTOCKUM | 1,000 tons | 52,493.78 | 23,202.22 | 6,674.90 | 10,3231.90 |
| TCDOM | 1,000 tons | 16,113.98 | 4,089.74 | 8,393.51 | 24,702.31 |
| RRPNW | $ / ton-mile | 0.014 | 0.001 | 0.011 | 0.018 |
| OCEANS | $ / m. ton | 9.56 | 3.11 | 0.91 | 15.95 |
| RRMR | $ / ton-mile | 0.038 | 0.008 | 0.026 | 0.077 |
| ***Illinois River*** | | | | | |
| BQIL | 1,000 tons | 1,364.49 | 589.02 | 293.50 | 3,324.55 |
| BRSP | $ / ton | 7.85 | 2.77 | 3.94 | 14.90 |
| CNILP | $ / ton | 90.56 | 23.28 | 61.07 | 173.57 |
| GSTOCKIL | 1,000 tons | 25,223.92 | 12,870.73 | 2,737.90 | 53,651.90 |
| OCEAN | $ / m. ton | 22.87 | 5.36 | 12.51 | 35.47 |
| RRGF | $ / ton | 9.52 | 1.80 | 6.32 | 17.43 |
| ***For Both Rivers*** | | | | | |
| GEXPQ | 1,000 tons | 4,615.70 | 1,158.33 | 2,287.21 | 7,310.14 |

* See the definition of the variables in Table 4.1.

**Table 4.3. Summary of OLS Grain Barge Demand Equations for Upper Mississippi River**

| Variables[1, 2] | Coefficient | t-statistic |
|---|---|---|
| $BQUM_{t-1}$ | 0.223 | 3.83*** |
| $BQUM_{t-12}$ | 0.304 | 2.75*** |
| $BRNI_{t}$ | -0.529 | -1.78* |
| $GEXPQ_{t}$ | 1.376 | 3.54*** |
| $GSTOCKUM_{t-1}$ | 0.035 | 0.21 |
| $TCDOM_{t}$ | -0.904 | -1.44 |
| $RRPNW_{t}$ | 0.386 | 0.48 |
| $OCEANS_{t}$ | -0.021 | -0.14 |
| $RRMR_{t}$ | -0.904 | -2.16** |
| CLOSURE | -2.022 | -6.06*** |
| FLOOD | -0.598 | -1.91** |
| CONSTANT | -3.297 | -0.54 |
| *Used Obs. (N)* | 84 | |
| *Adj. R^2* | 0.786 | |

[1] See Table 4.1 for definition of variables.
[2] All variables except WINTER and FLOOD are in natural log form.

***Significant at the 1% level, **significant at the 5% level, *significant at the 10% level.

**Table 4.4. Summary of 2SLS Grain Barge Demand Equations for Upper Mississippi River**

| Variables[1, 2] | Coefficient | t-statistic |
|---|---|---|
| $BQUM_{t-1}$ | 0.230 | 3.82*** |
| $BQUM_{t-12}$ | 0.328 | 2.76*** |
| $BRNI_t$ | -0.455 | -0.98 |
| $GEXPQ_t$ | 1.367 | 2.70** |
| $GSTOCKUM_{t-1}$ | 0.077 | 0.40 |
| $TCDOM_t$ | -0.350 | -0.91 |
| $RRPNW_t$ | -0.735 | -0.37 |
| $OCEANS_t$ | 0.145 | 0.67 |
| $RRMR_t$ | -0.412 | -0.45 |
| CLOSURE | -1.904 | -5.00*** |
| FLOOD | -0.650 | -1.95** |
| CONSTANT | -9.080 | -0.74 |
| *Used Obs. (N)* | 84 | |
| *Adj. R^2* | 0.775 | |

[1] See Table 4.1 for definition of variables.
[2] All variables except WINTER and FLOOD are in natural log form.

***Significant at the 1% level, **significant at the 5% level, *significant at the 10% level.

**Table 4.5. Summary of First-stage Regression of Barge Rate Equation (BRNI) in 2SLS Grain Barge Demand Equations for Upper Mississippi River**

| Variables[1, 2] | Coefficient | t-statistic |
|---|---|---|
| $BQUM_{t-1}$ | 0.001 | 0.04 |
| $BQUM_{t-12}$ | -0.027 | -0.88 |
| $BRNI_{t-1}$ | 0.739 | 6.89*** |
| $GEXPQ_{t}$ | 0.068 | 0.50 |
| $GSTOCKUM_{t-1}$ | -0.230 | -4.50*** |
| $TCDOM_{t}$ | 0.014 | 0.13 |
| $RRPNW_{t-1}$ | -0.111 | -0.48 |
| $OCEANS_{t-1}$ | 0.061 | 0.99 |
| $RRMR_{t-1}$ | -0.200 | -1.53 |
| CLOSURE | 0.066 | 0.66 |
| FLOOD | 0.098 | 1.08 |
| DIESEL | -0.468 | -2.09** |
| WAGE | 0.995 | 1.73* |
| CONSTANT | 1.663 | 0.69 |
| *Used Obs. (N)* | 84 | |
| *F-Statistic* | 15.62 | |
| *Adj. R^2* | 0.744 | |

[1] See Table 4.1 for definition of variables.
[2] All variables except WINTER and FLOOD are in natural log form.

***Significant at the 1% level, **significant at the 5% level, *significant at the 10% level.

**Table 4.6. Summary of First-stage Regression of Ocean Rates Spread Equation (OCEANS) in 2SLS Grain Barge Demand Equations for Upper Mississippi River**

| Variables[1, 2] | Coefficient | t-statistic |
|---|---|---|
| $BQUM_{t-1}$ | 0.001 | 0.04 |
| $BQUM_{t-12}$ | -0.019 | -0.53 |
| $BRNI_{t-1}$ | 0.276 | 2.22** |
| $GEXPQ_{t}$ | -0.221 | -1.42 |
| $GSTOCKUM_{t-1}$ | 0.040 | 0.67 |
| $TCDOM_{t}$ | -0.134 | -1.13 |
| $RRPNW_{t-1}$ | -0.363 | -1.35 |
| $OCEANS_{t-1}$ | 0.823 | 11.42*** |
| $RRMR_{t-1}$ | 0.045 | 0.30 |
| CLOSURE | 0.115 | 1.00 |
| FLOOD | -0.080 | -0.76 |
| DIESEL | 0.469 | 1.80* |
| WAGE | -1.062 | -1.59 |
| CONSTANT | 0.949 | 0.34 |
| *Used Obs. (N)* | 84 | |
| *F-Statistic* | 35.50 | |
| *Adj. R^2* | 0.87 | |

[1] See Table 4.1 for definition of variables.
[2] All variables except WINTER and FLOOD are in natural log form.

***Significant at the 1% level, **significant at the 5% level, *significant at the 10% level.

**Table 4.7. Summary of First-stage Regression of Rail Rate linking Minnesota and PNW (RRPNW) Equation in 2SLS Grain Barge Demand Equations for Upper Mississippi River**

| Variables[1, 2] | Coefficient | t-statistic |
|---|---|---|
| $BQUM_{t-1}$ | 0.005 | 0.664 |
| $BQUM_{t-12}$ | 0.009 | 0.606 |
| $BRNI_{t-1}$ | 0.008 | 0.164 |
| $GEXPQ_{t}$ | 0.074 | 1.142 |
| $GSTOCKUM_{t-1}$ | -0.022 | -0.913 |
| $TCDOM_{t}$ | 0.040 | 0.805 |
| $RRPNW_{t-1}$ | 0.384 | 3.435*** |
| $OCEANS_{t-1}$ | 0.041 | 1.356 |
| $RRMR_{t-1}$ | 0.034 | 0.544 |
| CLOSURE | 0.054 | 1.129 |
| FLOOD | -0.000 | -0.008 |
| DIESEL | -0.088 | -0.819 |
| WAGE | -0.174 | -0.630 |
| CONSTANT | -2.485 | -2.153 |
| *Used Obs. (N)* | 84 | |
| *F-Statistic* | 3.52 | |
| *Adj. R^2* | 0.28 | |

[1] See Table 4.1 for definition of variables.
[2] All variables except WINTER and FLOOD are in natural log form.

***Significant at the 1% level, **significant at the 5% level, *significant at the 10% level.

**Table 4.8. Summary of First-stage Regression of Rail Rate of Minnesota to the Mississippi River (RRMR) Equation in 2SLS Grain Barge Demand Equations for Upper Mississippi River**

| Variables[1, 2] | Coefficient | t-statistic |
|---|---|---|
| $BQUM_{t-1}$ | -0.015 | -1.00 |
| $BQUM_{t-12}$ | -0.029 | -1.05 |
| $BRNI_{t-1}$ | -0.132 | -1.36 |
| $GEXPQ_{t}$ | 0.113 | 0.93 |
| $GSTOCKUM_{t-1}$ | -0.070 | -1.52 |
| $TCDOM_{t}$ | -0.120 | -1.30 |
| $RRPNW_{t-1}$ | 0.227 | 1.08 |
| $OCEANS_{t-1}$ | -0.060 | -1.07 |
| $RRMR_{t-1}$ | 0.198 | 1.68* |
| CLOSURE | -0.091 | -1.00 |
| FLOOD | 0.149 | 1.82* |
| DIESEL | 0.241 | 1.19 |
| WAGE | 1.477 | 2.84*** |
| CONSTANT | -5.317 | -2.45 |
| *Used Obs. (N)* | 84 | |
| *F-Statistic* | 3.33 | |
| *Adj. R^2* | 0.38 | |

[1] See Table 4.1 for definition of variables.
[2] All variables except WINTER and FLOOD are in natural log form.

***Significant at the 1% level, **significant at the 5% level, *significant at the 10% level.

**Table 4.9. Summary of OLS Grain Barge Demand Equations for Illinois River**

| Variables[1, 2] | Coefficient | t-statistic |
|---|---|---|
| $BQIL_{t-12}$ | 0.353 | $4.37^{***}$ |
| $BRSP_t$ | -0.236 | $-2.29^{**}$ |
| $GEXPQ_t$ | 0.762 | $6.55^{***}$ |
| $CNILP_t$ | -0.426 | $-3.24^{***}$ |
| $GSTOCKIL_{t-1}$ | 0.032 | 0.60 |
| $RRGF_t$ | -0.067 | -0.41 |
| $OCEAN_t$ | 0.260 | $2.28^{**}$ |
| WINTER | 0.252 | $2.96^{***}$ |
| CONSTANT | -0.414 | -0.39 |
| | | |
| *Used Obs. (N)* | 84 | |
| *Adj. R^2* | 0.73 | |

[1] See Table 4.1 for definition of variables.
[2] All variables except WINTER and FLOOD are in natural log form.

$^{***}$Significant at the 1% level, $^{**}$significant at the 5% level, $^{*}$significant at the 10% level.

**Table 4.10. Summary of 2SLS Grain Barge Demand Equations for Illinois River**

| Variables[1, 2] | Coefficient | t-statistic |
|---|---|---|
| $BQIL_{t-12}$ | 0.365 | 4.31*** |
| $BRIL_{t}$ | -0.241 | -1.38 |
| $GEXPQ_{t}$ | 0.808 | 6.08*** |
| $CNILP_{t}$ | -0.364 | -1.87* |
| $GSTOCKIL_{t-1}$ | 0.015 | 0.26 |
| $RRGF_{t}$ | -0.401 | -0.78 |
| $OCEAN_{t}$ | 0.208 | 1.32 |
| WINTER | 0.252 | 2.82*** |
| CONSTANT | -0.072 | -0.06 |
| *Used Obs. (N)* | 84 | |
| *Adj. R^2* | 0.74 | |

[1] See Table 4.1 for definition of variables.
[2] All variables except WINTER and FLOOD are in natural log form.

***Significant at the 1% level, **significant at the 5% level, *significant at the 10% level.

**Table 4.11. Summary of Barge Rate (BRSP) Equation in the First Stage of 2SLS Grain Barge Demand Equations for Illinois River**

| Variables[1, 2] | Coefficient | t-statistic |
|---|---|---|
| $BQIL_{t-12}$ | 0.063 | 0.94 |
| $BRSP_{t-1}$ | 0.615 | 7.20*** |
| $GEXPQ_{t}$ | 0.128 | 1.13 |
| $CNILP_{t}$ | -0.246 | -2.29** |
| $GSTOCKIL_{t-1}$ | -0.269 | -6.46*** |
| $RRGF_{t-1}$ | -0.382 | -2.60** |
| $OCEAN_{t-1}$ | 0.424 | 3.27*** |
| WINTER | 0.166 | 2.38** |
| DIESEL | -0.566 | -2.88*** |
| WAGE | 1.250 | 1.95** |
| CONSTANT | 2.893 | 1.52 |
| | | |
| *Used Obs. (N)* | 84 | |
| *F-Statistic* | 22.53 | |
| *Adj. R^2* | 0.72 | |

[1] See Table 4.1 for definition of variables.
[2] All variables except WINTER and FLOOD are in natural log form.

***Significant at the 1% level, **significant at the 5% level, *significant at the 10% level.

**Table 4.12. Summary of Ocean Rate (OCEAN) Equation in the First Stage of 2SLS Grain Barge Demand Equations for Illinois River**

| Variables[1, 2] | Coefficient | t-statistic |
|---|---|---|
| $BQIL_{t-12}$ | -0.021 | -0.84 |
| $BRSP_{t-1}$ | 0.046 | 1.46 |
| $GEXPQ_{t}$ | -0.007 | -0.17 |
| $CNILP_{t}$ | -0.110 | -2.80*** |
| $GSTOCKIL_{t-1}$ | -0.005 | -0.32 |
| $RRGF_{t-1}$ | 0.069 | 1.27 |
| $OCEAN_{t-1}$ | 0.900 | 18.94*** |
| WINTER | 0.028 | 1.09 |
| DIESEL | 0.144 | 2.00** |
| WAGE | -0.537 | -2.29** |
| CONSTANT | 1.282 | 1.84 |
| *Used Obs. (N)* | 84 | |
| *F-Statistic* | 111.08 | |
| *Adj. R^2* | 0.93 | |

[1] See Table 4.1 for definition of variables.
[2] All variables except WINTER and FLOOD are in natural log form.

***Significant at the 1% level, **significant at the 5% level, *significant at the 10% level.

**Table 4.13. Summary of Rail Rate (RRGF) Equation in the First Stage of 2SLS Grain Barge Demand Equations for Illinois River**

| Variables[1, 2] | Coefficient | t-statistic |
|---|---|---|
| $BQIL_{t-12}$ | 0.038 | 0.69 |
| $BRSP_{t-1}$ | 0.129 | 1.83* |
| $GEXPQ_{t}$ | -0.069 | -0.74 |
| $CNILP_{t}$ | 0.184 | 2.08** |
| $GSTOCKIL_{t-1}$ | -0.039 | -1.12 |
| $RRGF_{t-1}$ | 0.135 | 1.11 |
| $OCEAN_{t-1}$ | 0.004 | 0.04 |
| WINTER | 0.024 | 0.42 |
| DIESEL | -0.036 | -0.22 |
| WAGE | 1.097 | 2.07** |
| CONSTANT | -1.074 | -0.68 |
| *Used Obs. (N)* | 84 | |
| *F-Statistic* | 2.82 | |
| *Adj. R^2* | 0.18 | |

[1] See Table 4.1 for definition of variables.
[2] All variables except WINTER and FLOOD are in natural log form.

***Significant at the 1% level, **significant at the 5% level, *significant at the 10% level.

**Table 4.14. Lower Triangular of the Covariance Matrix**

| | BQUM* | BQIL |
|---|---|---|
| BQUM | 0.374 | |
| BQIL | 0.008 | 0.509 |

* See Table 4.1 for definition of variables.

# APPENDIX B

# FIGURES

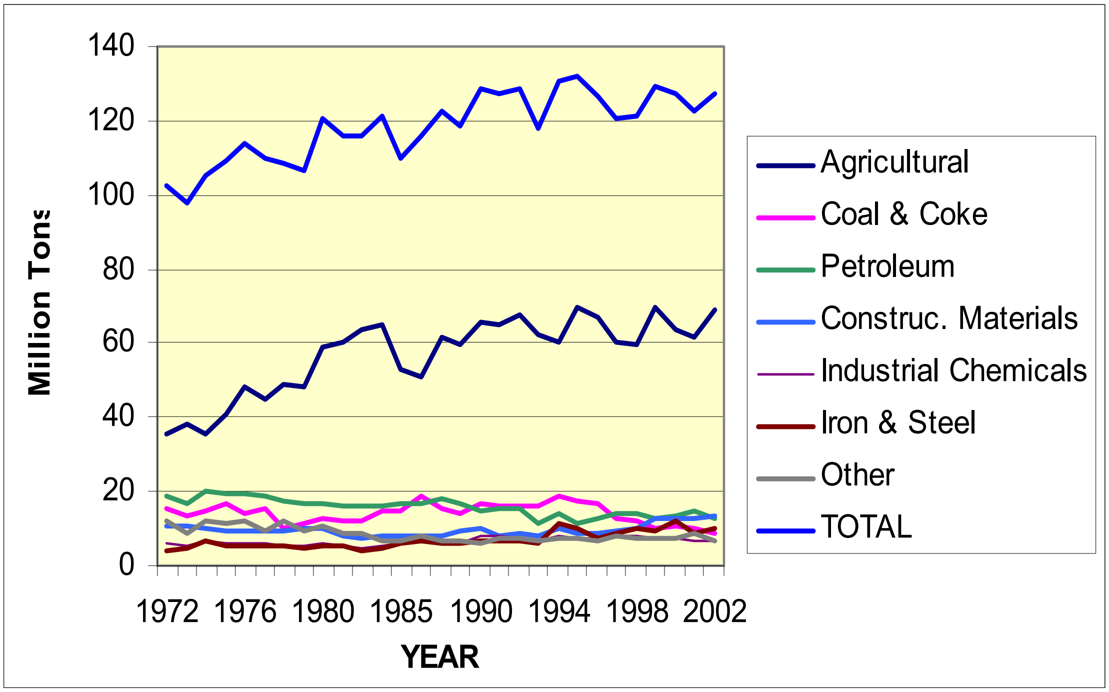



**Figure 1.1. Comparative Tonnages of Commodities Shipped by Barge on the Upper Mississippi River and Illinois Waterway, 1972-2002**

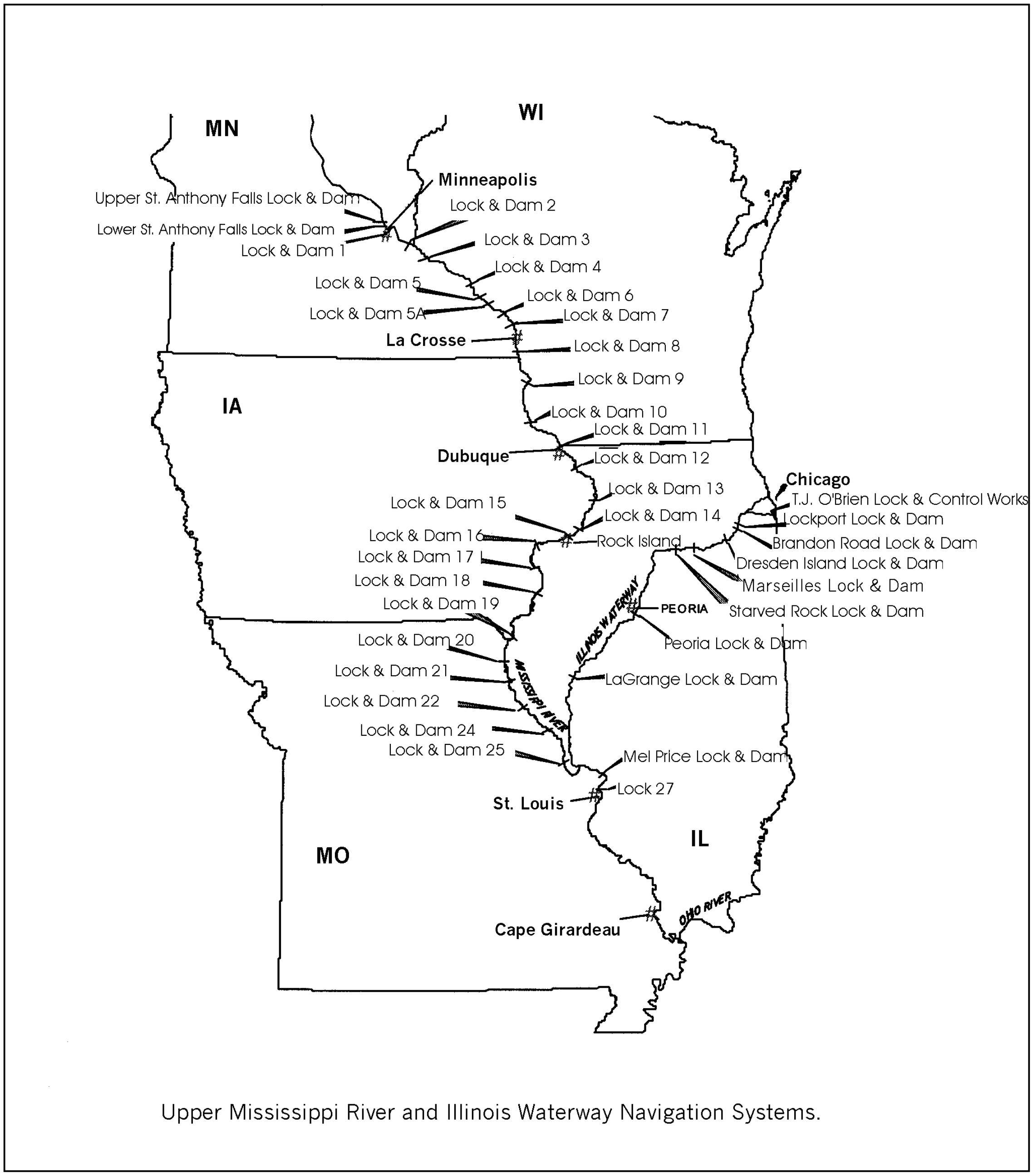
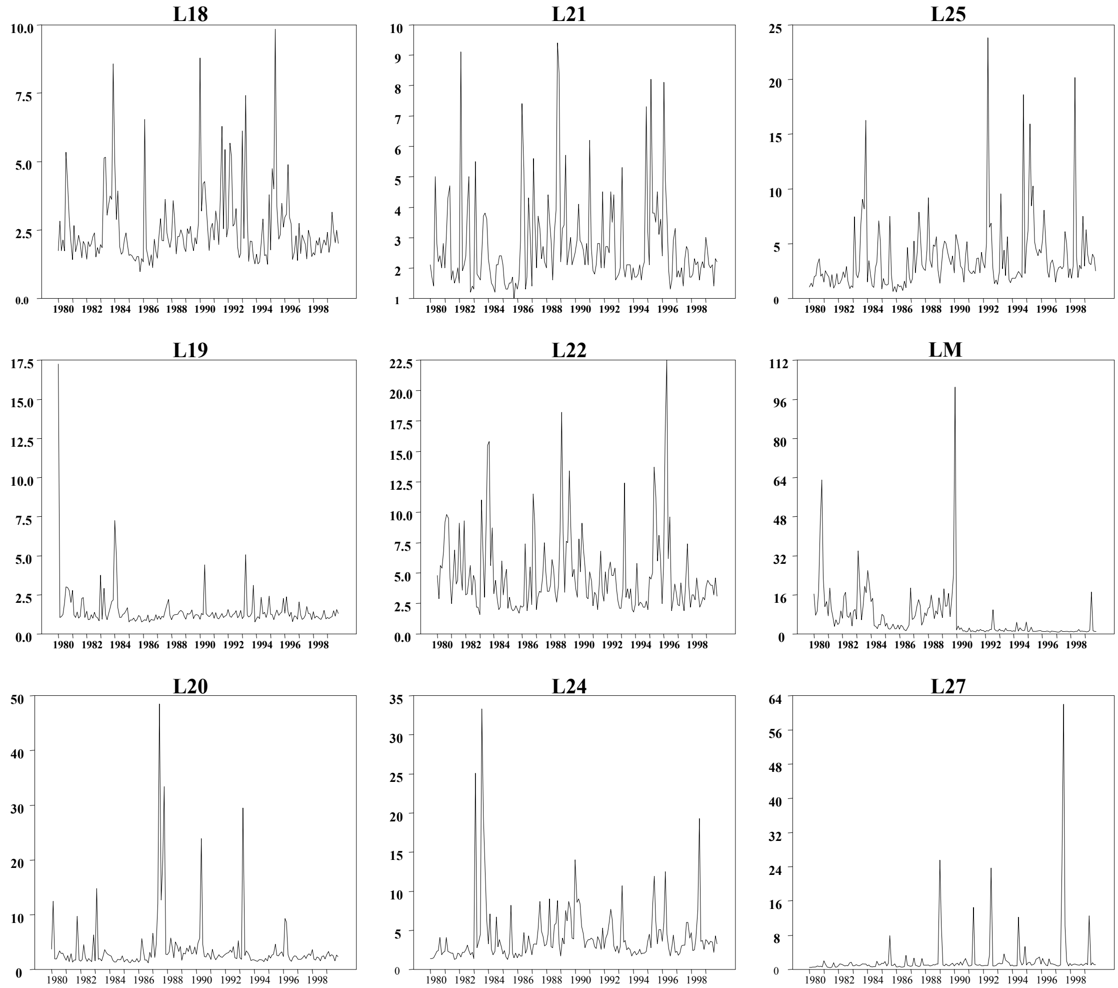



**Figure 2.1. Map of Upper Mississippi and Illinois Rivers with Locks and Dams**




* L18 = AVG DELAY AT LOCK 18
* L19 = AVG DELAY AT LOCK 19
* L20 = AVG DELAY AT LOCK 20
* L21 = AVG DELAY AT LOCK 21
* L22 = AVG DELAY AT LOCK 22
* L24 = AVG DELAY AT LOCK 24
* L25 = AVG DELAY AT LOCK 25
* LMP = AVG DELAY AT LOCK MELVIN PRINCE
* L27 = AVG DELAY AT LOCK 27

**Figure 2.2. Plots of Delays at Selected Locks on the Upper Mississippi and Illinois Rivers**

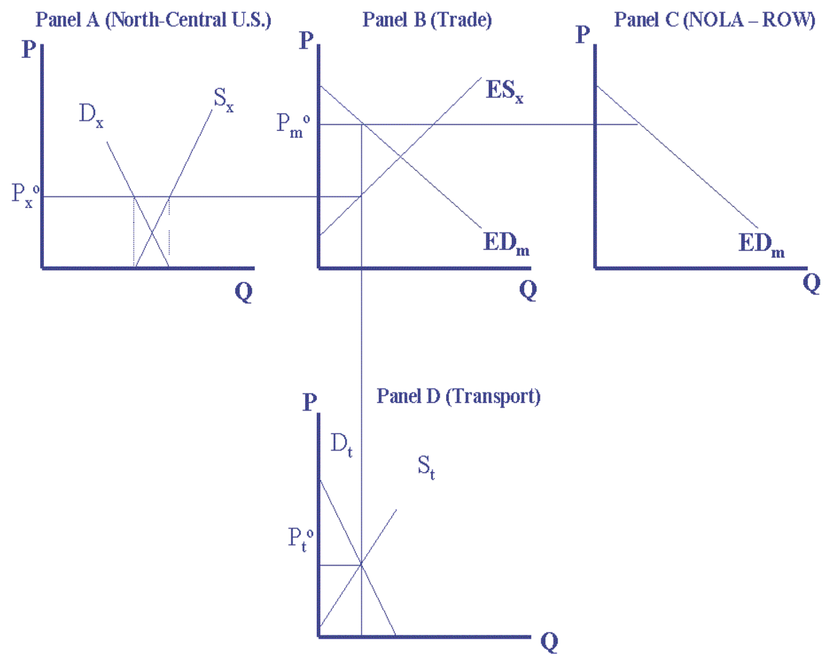



**Figure 2.3. Two-region Spatial Equilibrium Model and Derived Transportation Market**

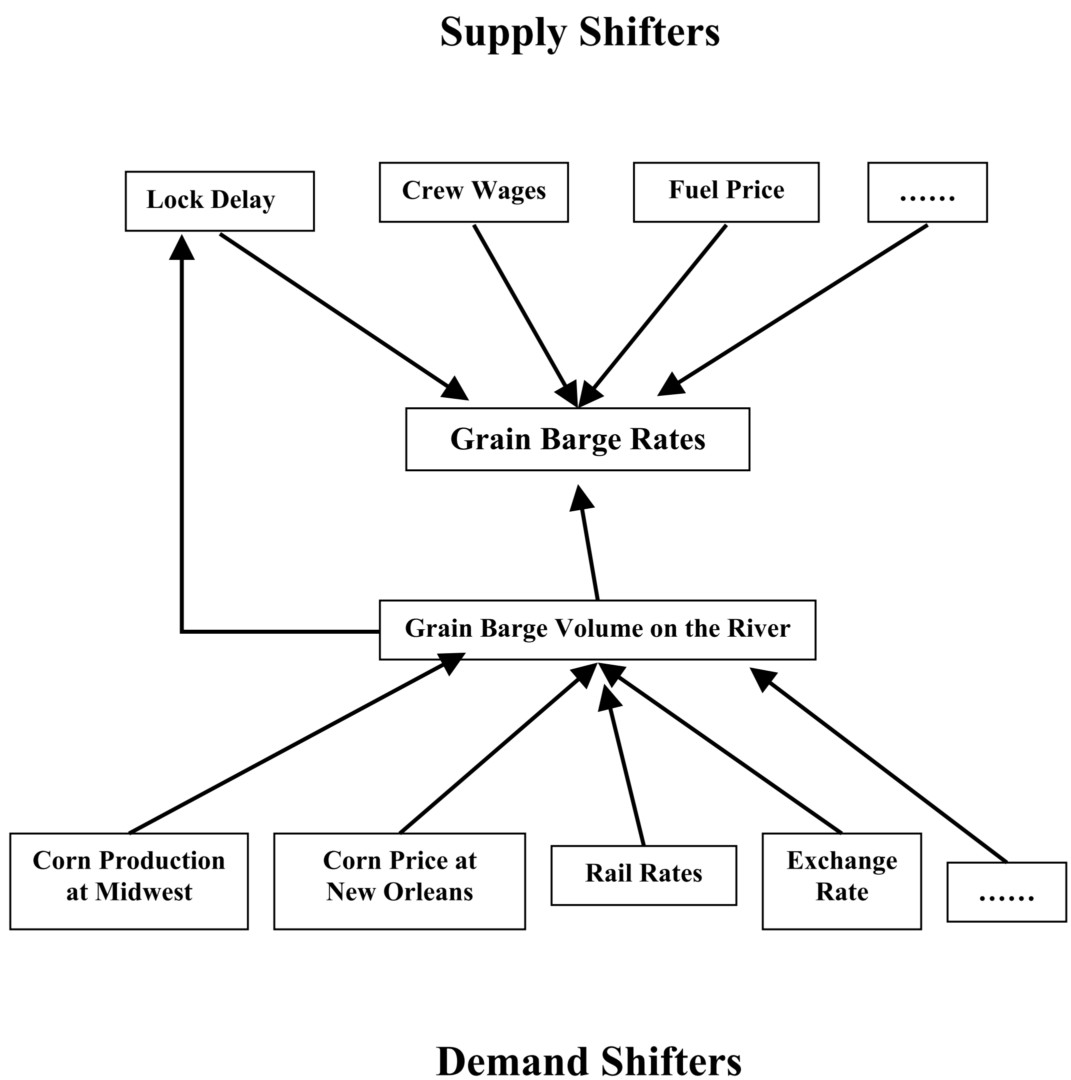



**Figure 2.4. Possible Factors Affecting Lock Delays on the Upper Mississippi and Illinois Rivers**

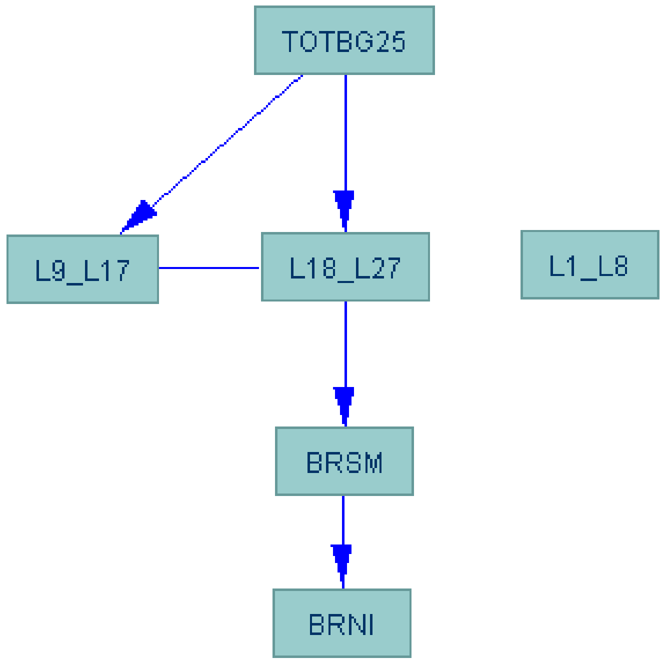



**Figure 2.5. Directed Graph of Forces that Cause the Grain Barge Rate on the Upper Mississippi River from a VAR Model: Accumulated Lock Delay by River Segment and Traffic Levels as Casual Forces**

* See Table 2.1 for definition of variables.

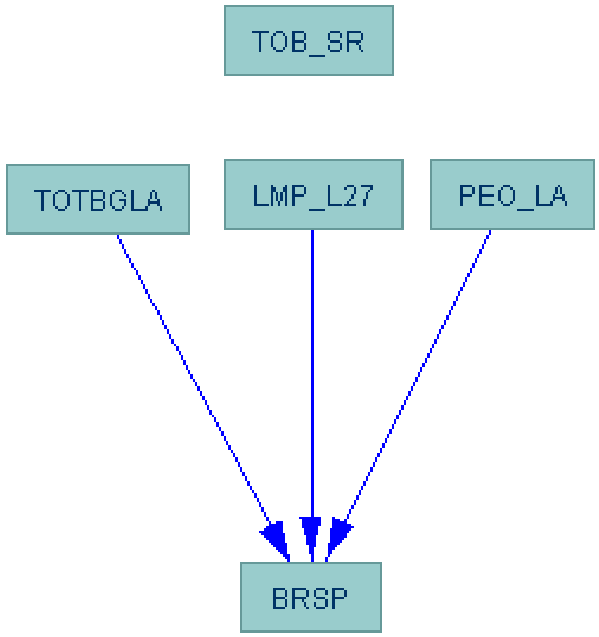



**Figure 2.6. Directed Graph of Forces that Cause the Grain Barge Rate on the Illinois River from a VAR Model: Accumulated Lock Delay by River Segment and Traffic Levels as Casual Forces**

[*] See Table 2.1 for definition of variables.

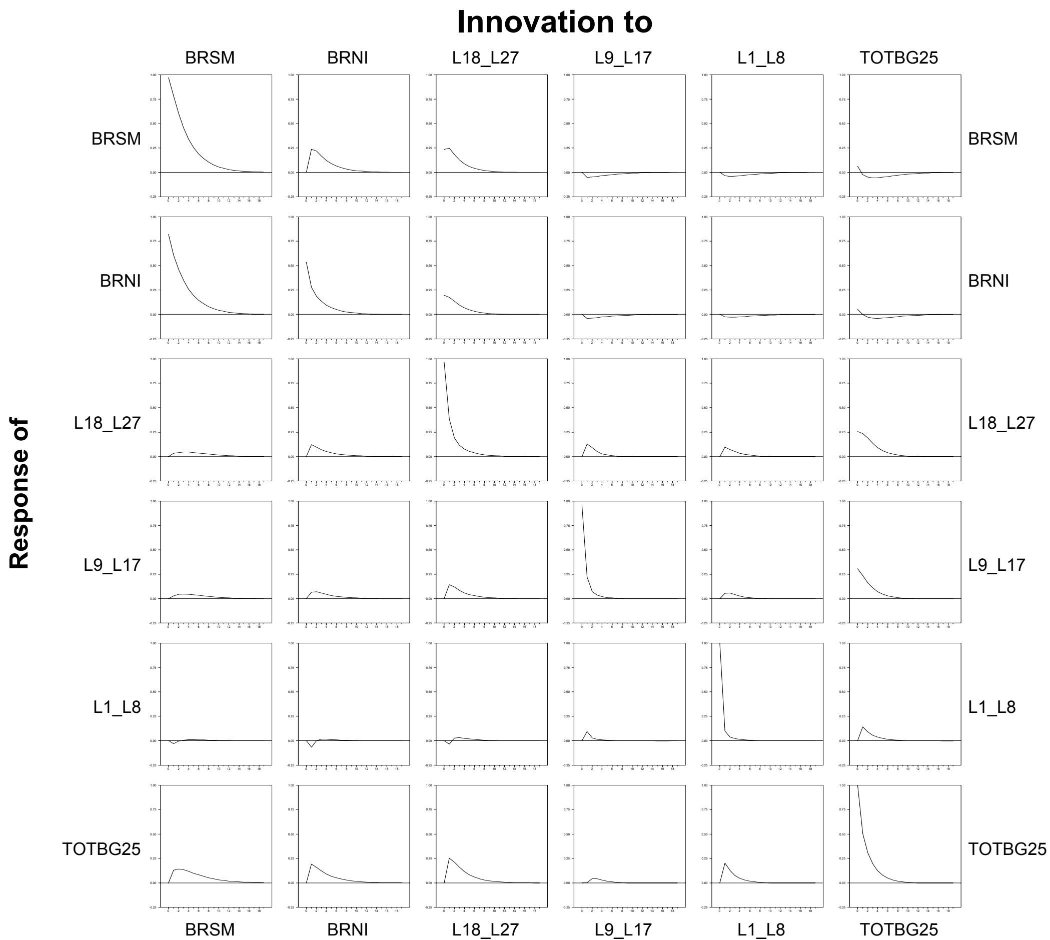



**Figure 2.7. Normalized Responses of Grain Barges, Lock Delays and Traffic Levels on the Upper Mississippi River to a One-Time-Only Shock (Innovation) in Every Other Series over Horizons of 0 to 9 Months**

[*] See Table 2.1 for definition of variables

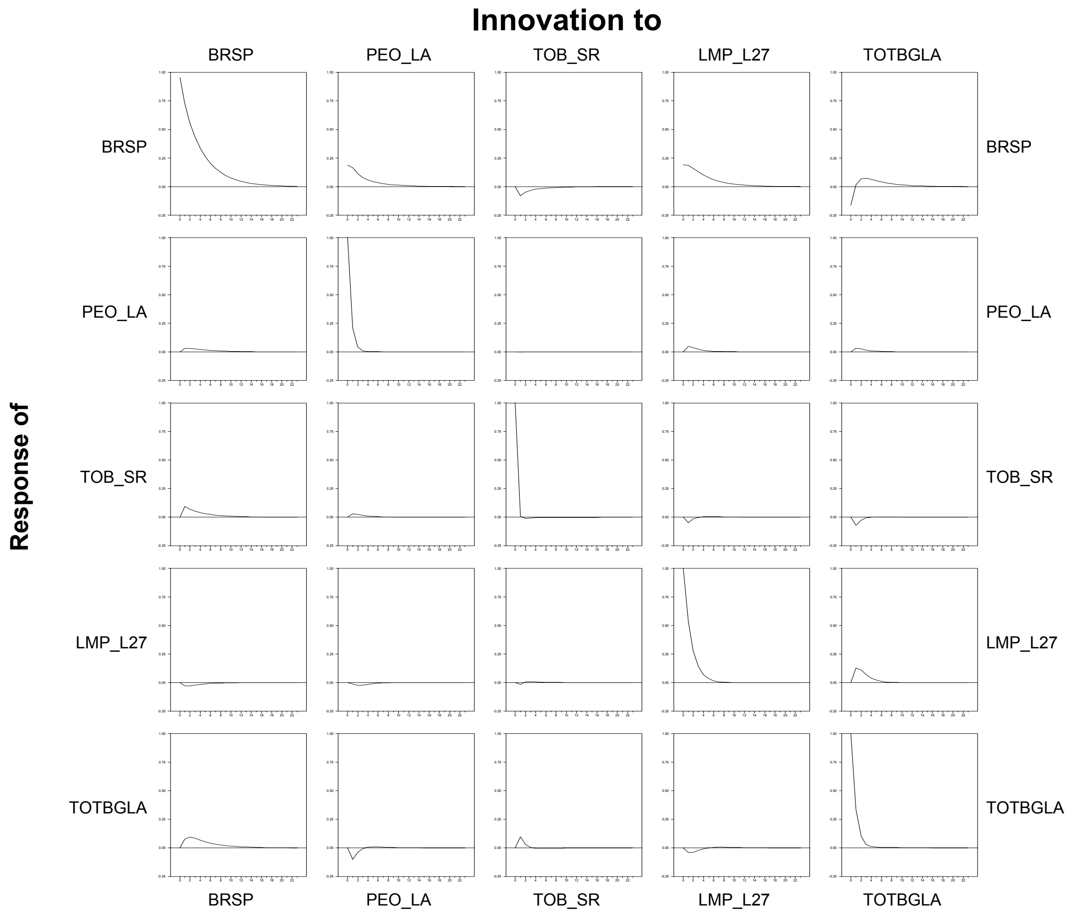



**Figure 2.8. Normalized Responses of Grain Barges, Lock Delays and Traffic Levels on the Illinois River to a One-Time-Only Shock (Innovation) in Every Other Series over Horizons of 0 to 12 Months**

* See Table 2.1 for definition of variables.

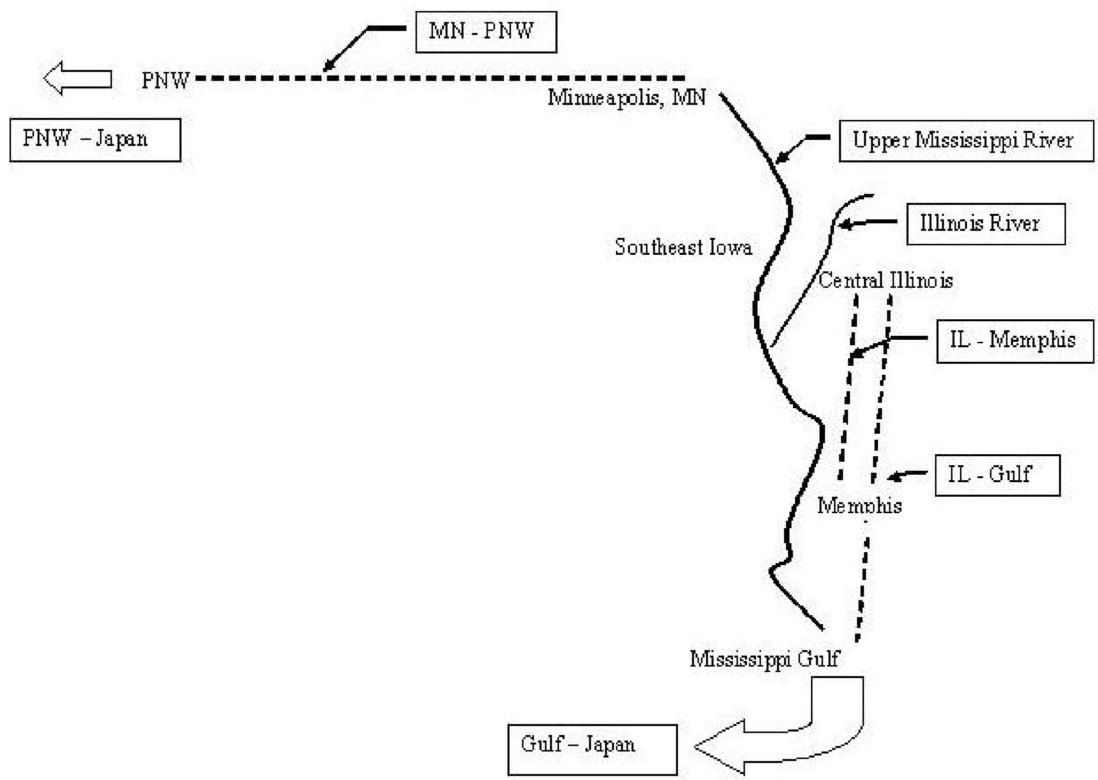



**Figure 3.1. Spatial Arrangement of Prices, Rates and Quantities Analyzed via Time-Series Methods**

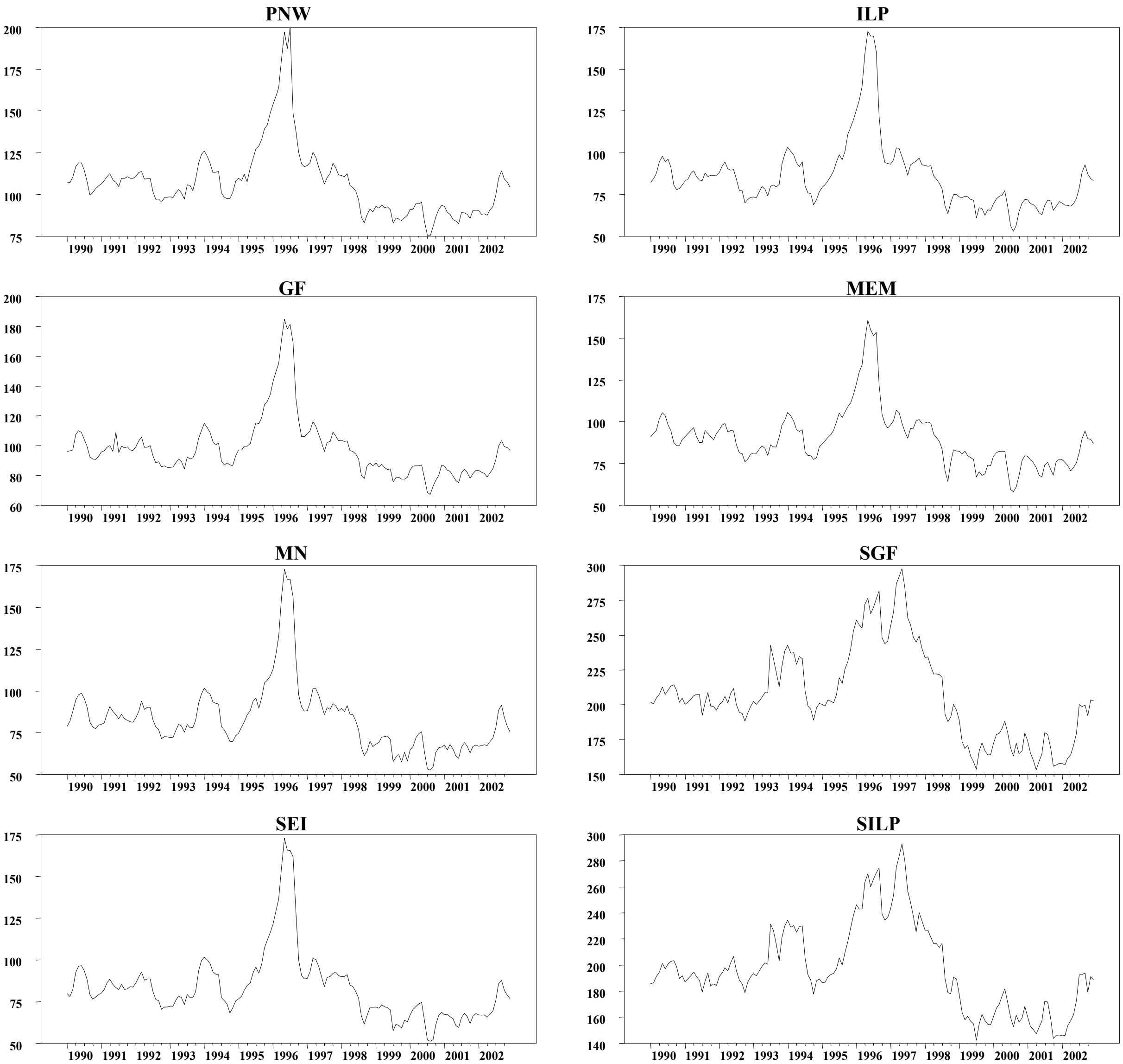



**Figure 3.2. Plots of Six Monthly Corn Prices and Two Soybean Prices, 1990-2002**

* See Table 3.1 for definition of variables.

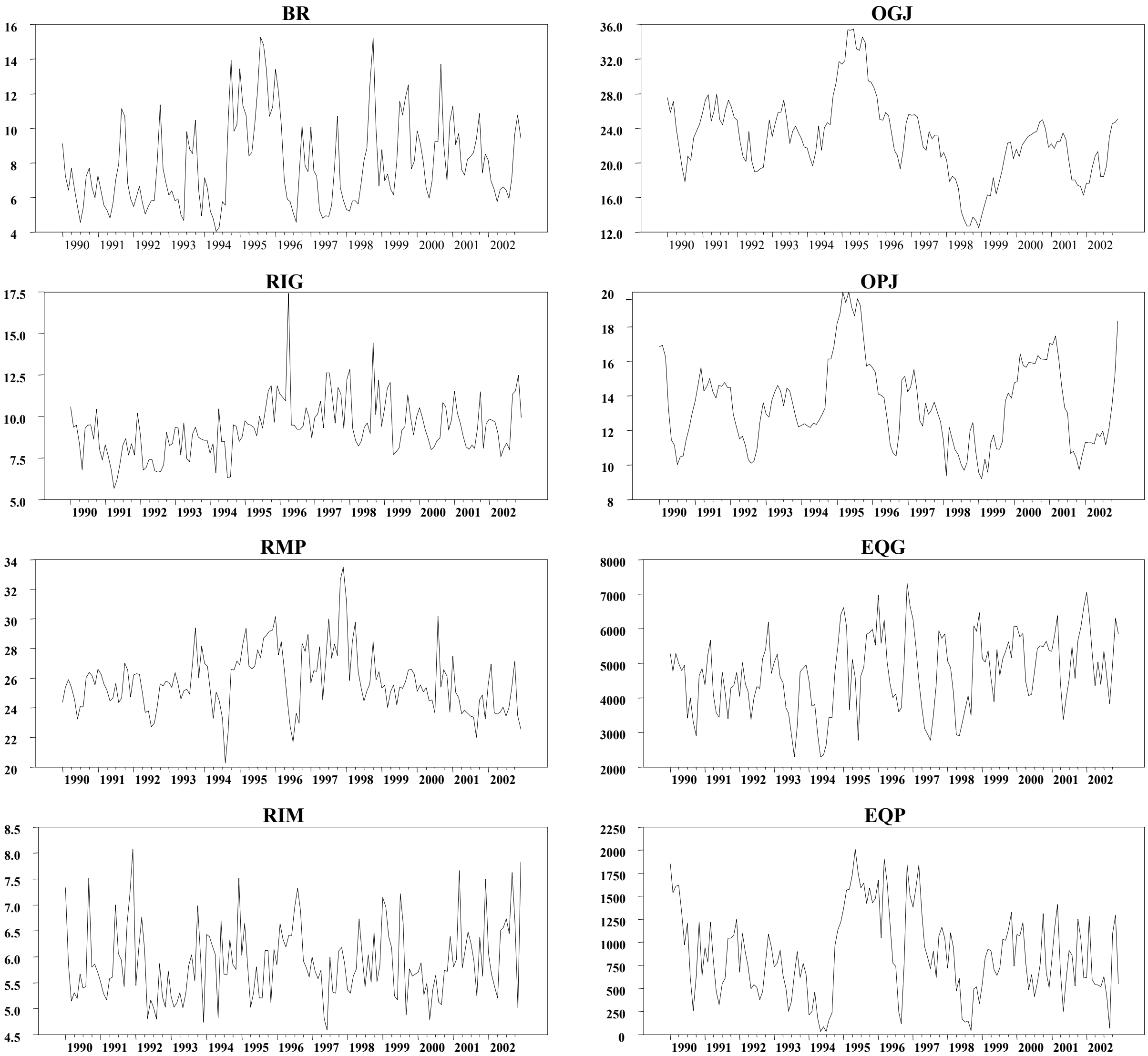



**Figure 3.3. Plots of Six Monthly Transportation Rates and Two Grain Exports, 1990-2002**

* See Table 3.1 for definition of variables.

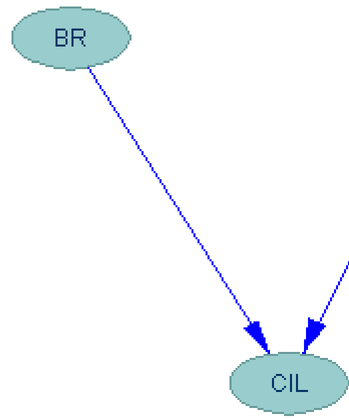



**Figure 3.4. Directed Acyclic Graph on Innovations from Central Illinois Corn Prices, Mississippi Gulf, and Barge Rates with a Three-Lag VAR**

* See Table 3.1 for definition of variables.

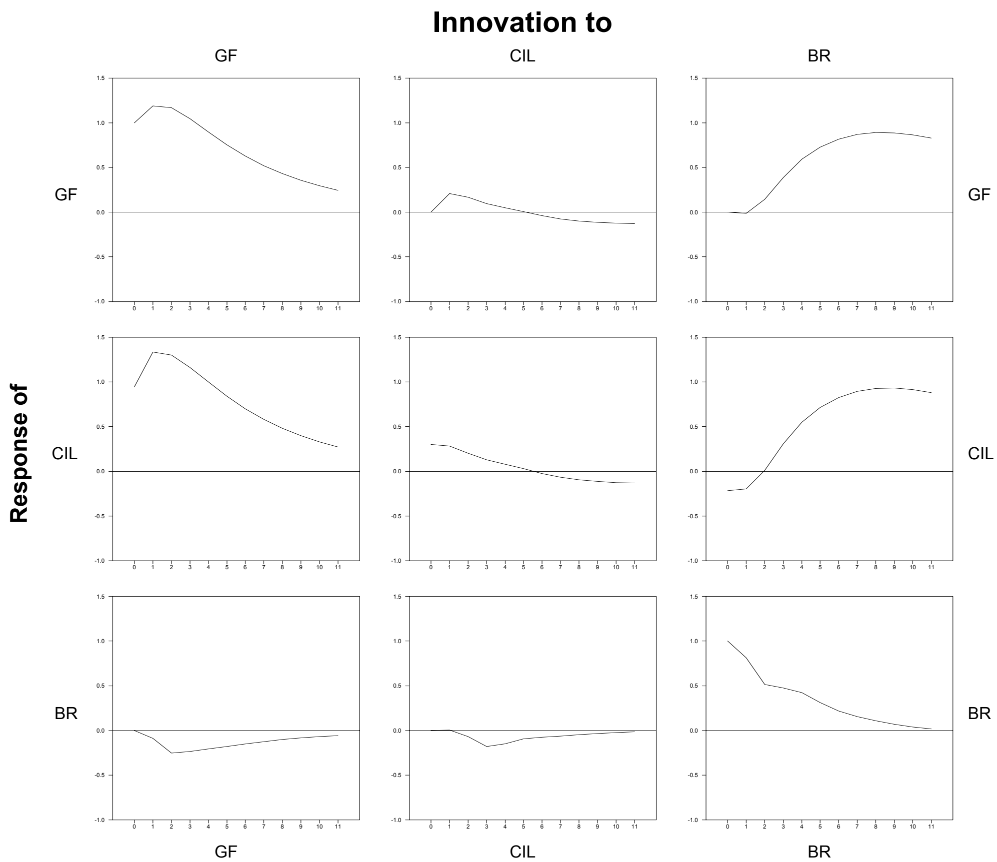



**Figure 3.5. Normalized Responses of Each Series to a One-Time-Only Shock (Innovation) in Each Price and Rate over Horizons of 0 to 12 Months**

* See Table 3.1 for definition of variables.

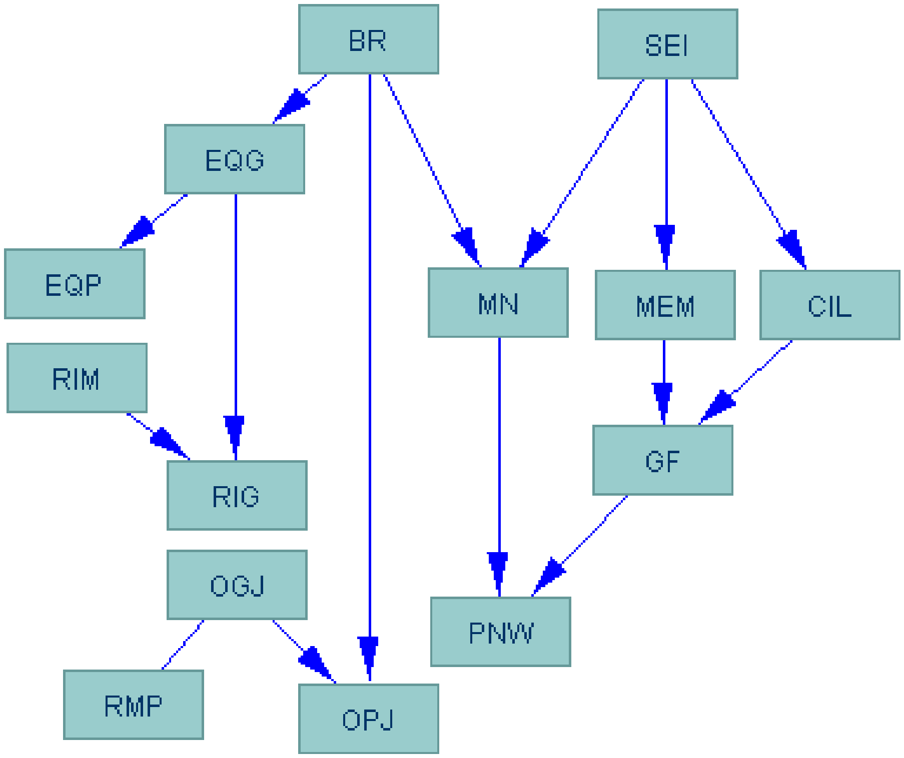



**Figure 3.6. Directed Acyclic Graph on Innovations from Fourteen Series of Corn Prices, Transportation Rates, and Grain Exports with a Two-Lag VAR**

* See Table 3.1 for definition of variables.

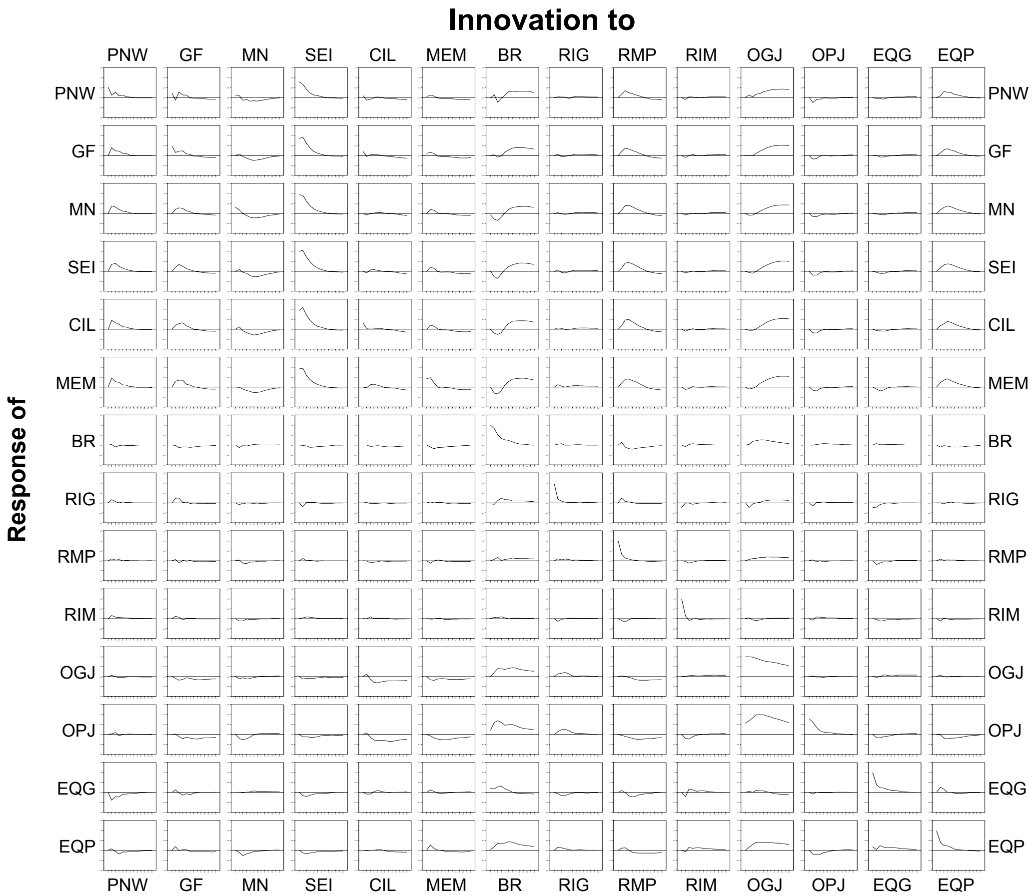



**Figure 3.7. Normalized Responses of Each Series to a One-Time-Only Shock (Innovation) in Fourteen Corn Prices, Transportation Rates, and Grain Exports with a Two-Lag VAR over Horizons of 0 to 12 Months**

* See Table 3.1 for definition of variables.

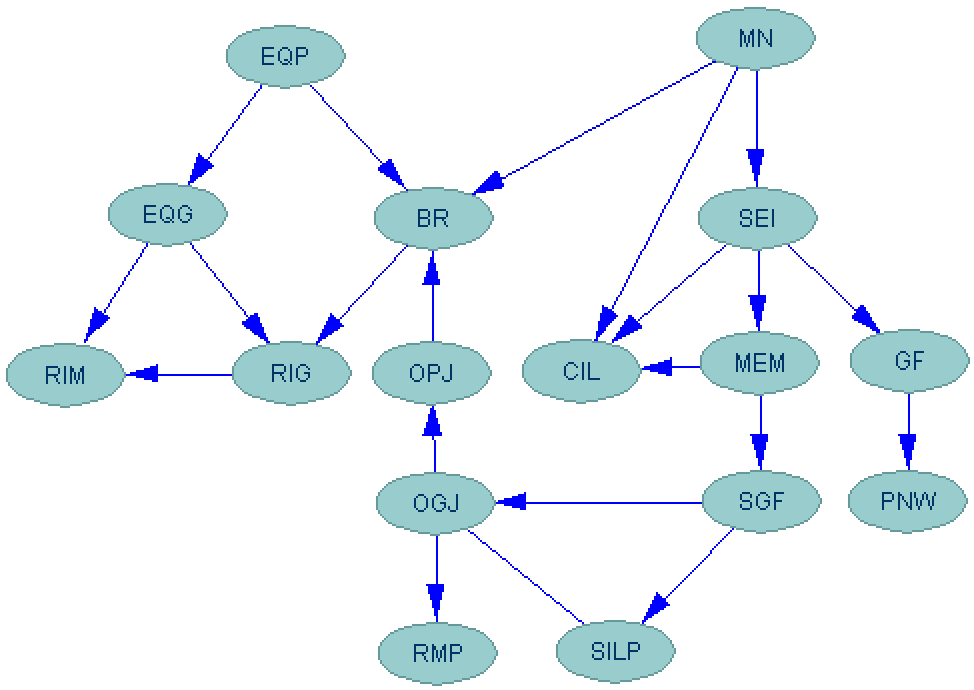



**Figure 3.8. Directed Acyclic Graph on Weighted Average Innovations from Sixteen Series of Corn Prices, Soybean Prices, Transportation Rates, and Grain Exports**

* See Table 3.1 for definition of variables.

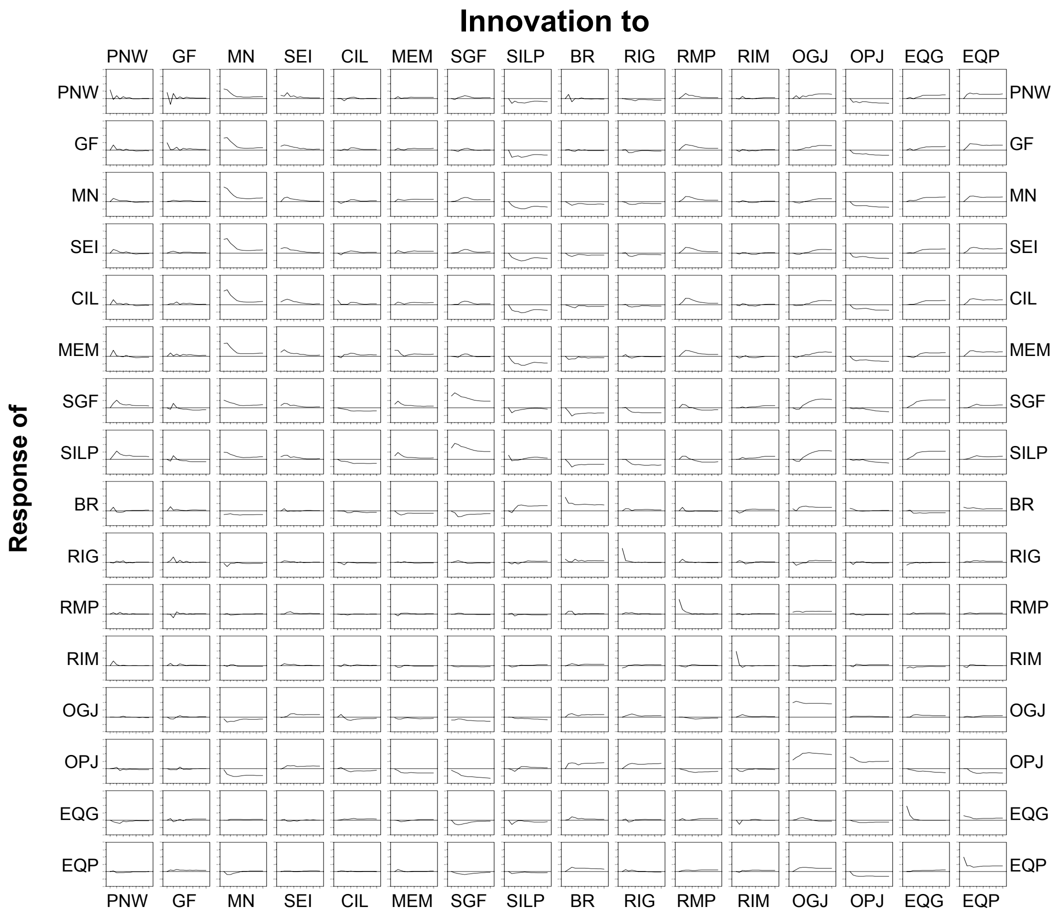



**Figure 3.9. Normalized Responses of Each Series to a One-Time-Only Shock (Innovation) in Sixteen Corn Prices, Soybean Prices, Transportation Rates, and Grain Exports with a Two-Lag ECM over Horizons of 0 to 12 Months**

* See Table 3.1 for definition of variables.

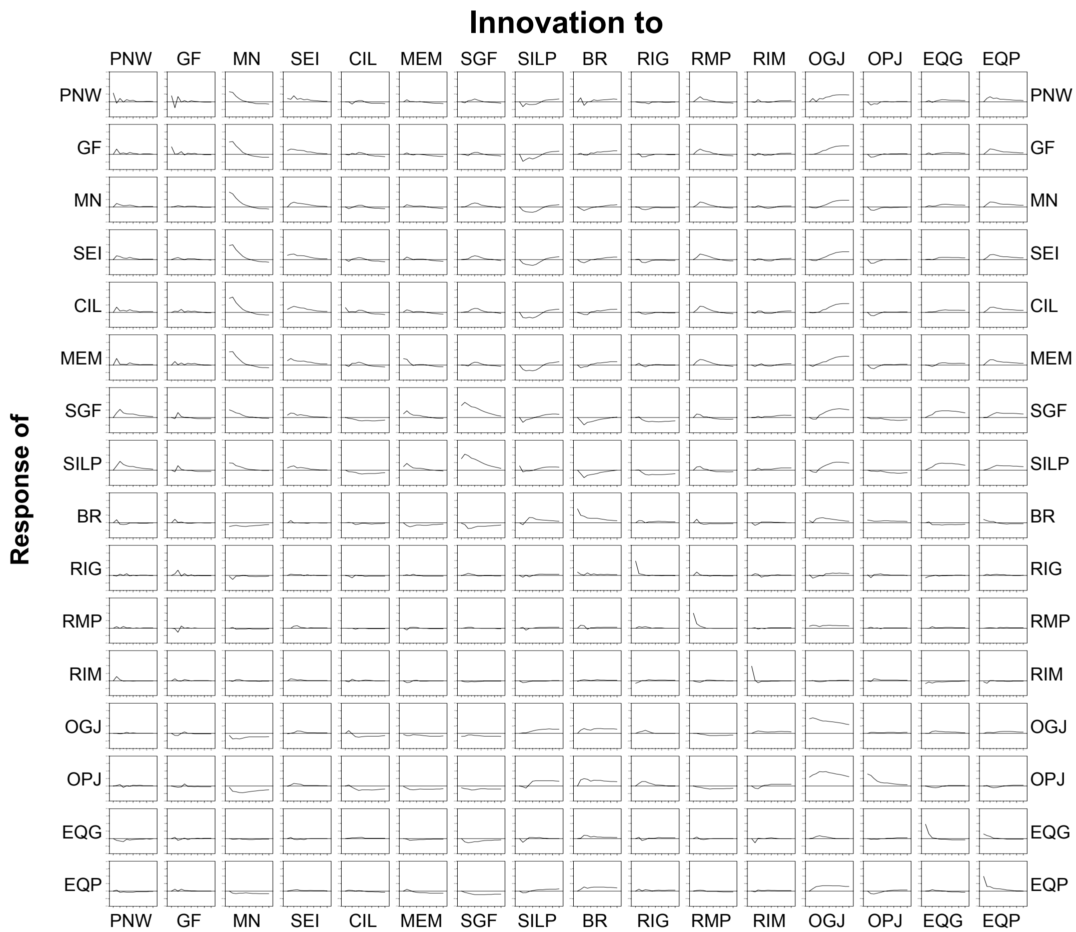



**Figure 3.10. Normalized Responses of Each Series to a One-Time-Only Shock (Innovation) in Sixteen Corn Prices, Soybean Prices, Transportation Rates, and Grain Exports with a Two-Lag VAR over Horizons of 0 to 12 Months**

* See Table 3.1 for definition of variables.

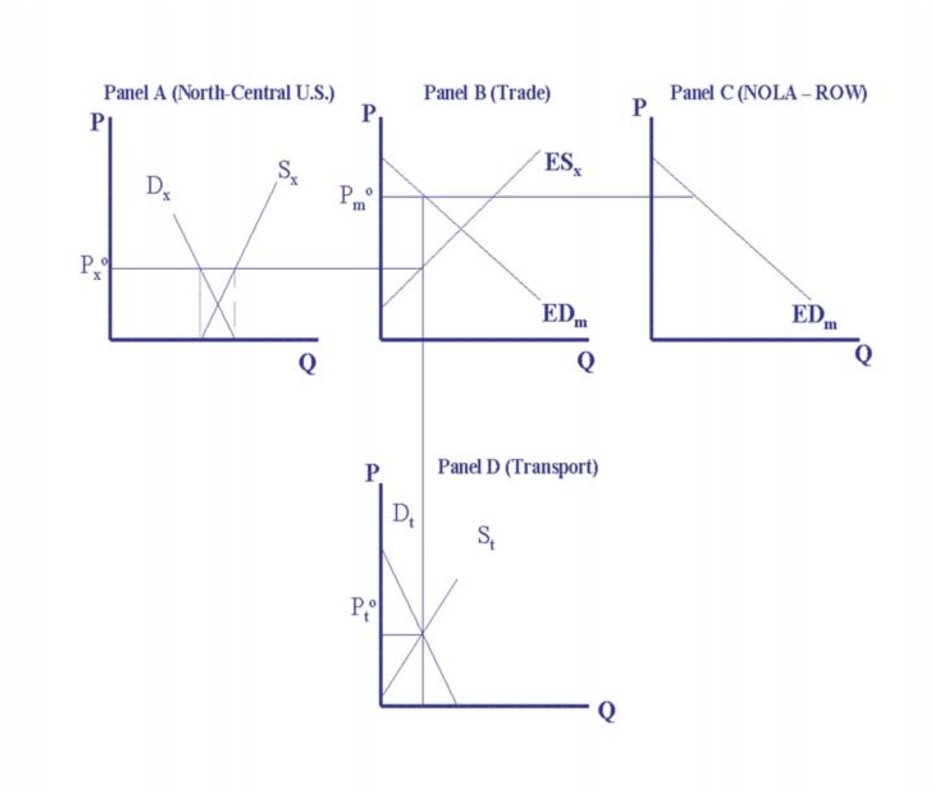



**Figure 4.1. A Simplified Spatial Equilibrium Model and Transportation Market**

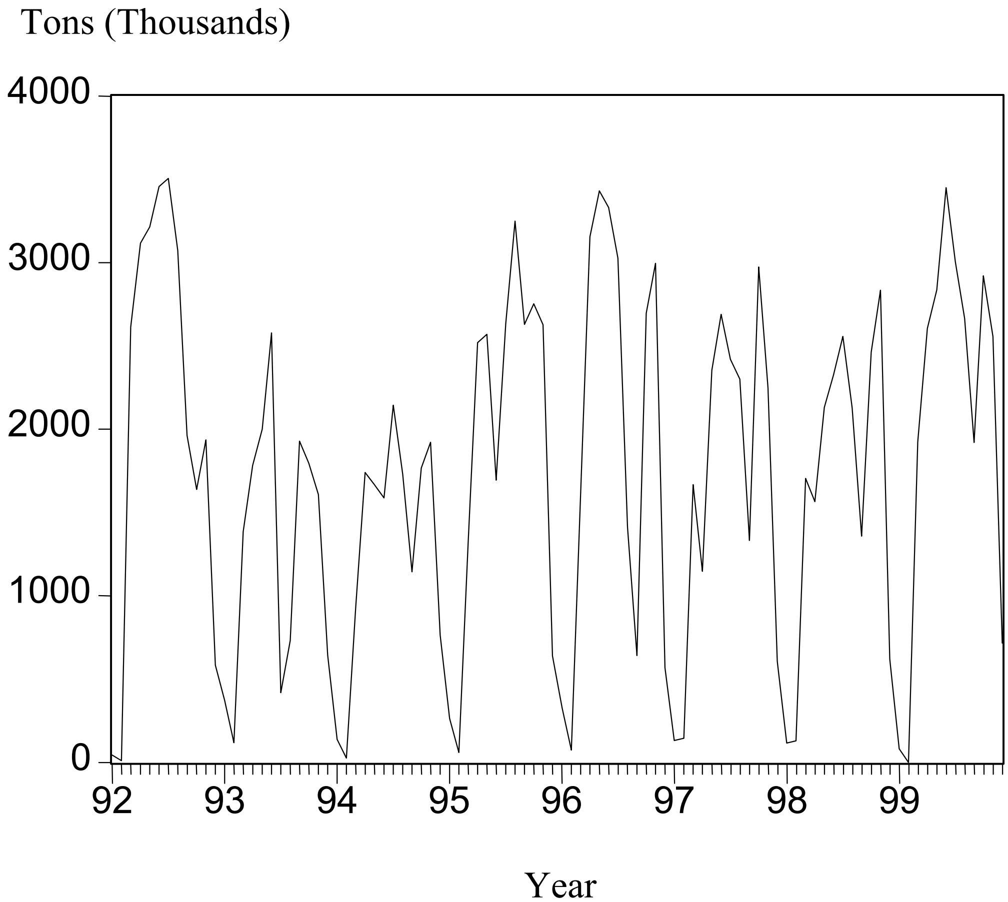



**Figure 4.2. Quantity of Corn and Soybeans Moved by Barge on the Upper Mississippi River, Thousand of Tons**

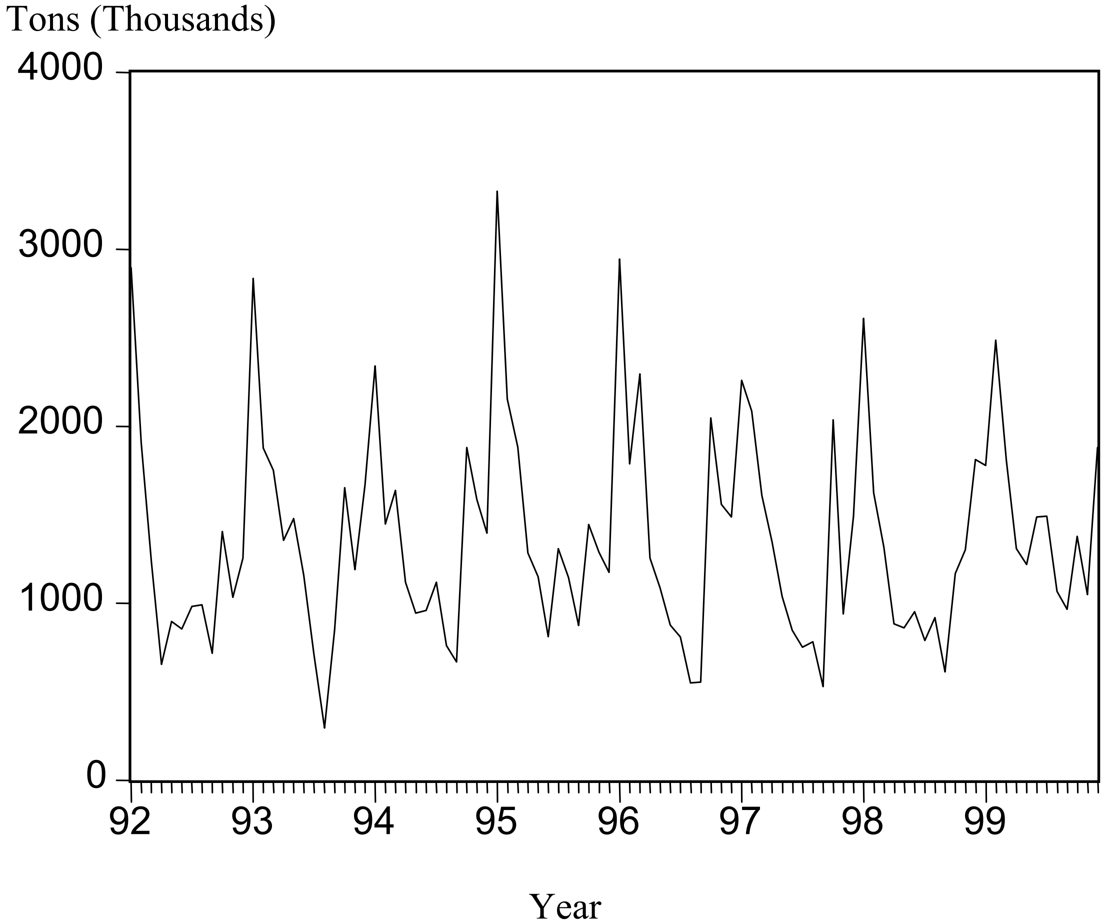



**Figure 4.3. Quantity of Corn and Soybeans Moved by Barge on the Illinois River, Thousand of Tons**

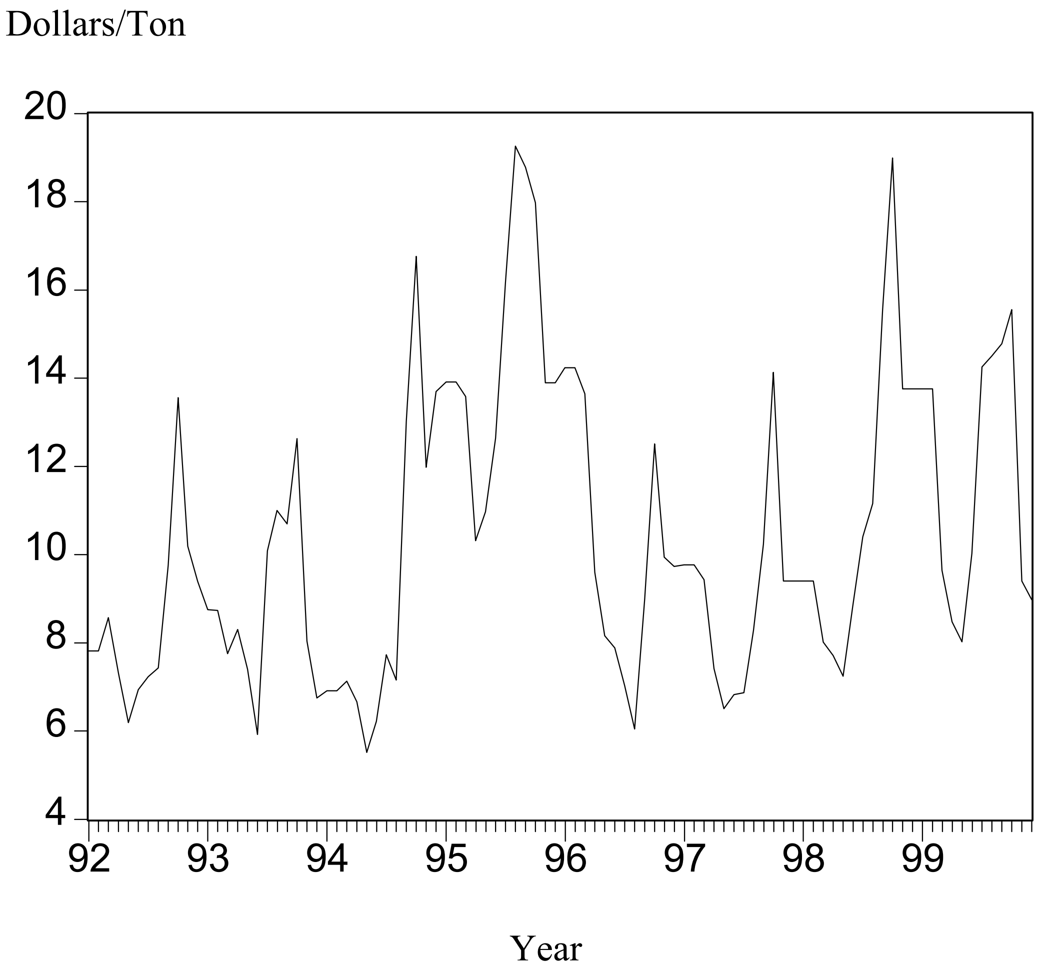



**Figure 4.4. North Iowa Grain Barge Rate on the Upper Mississippi River**

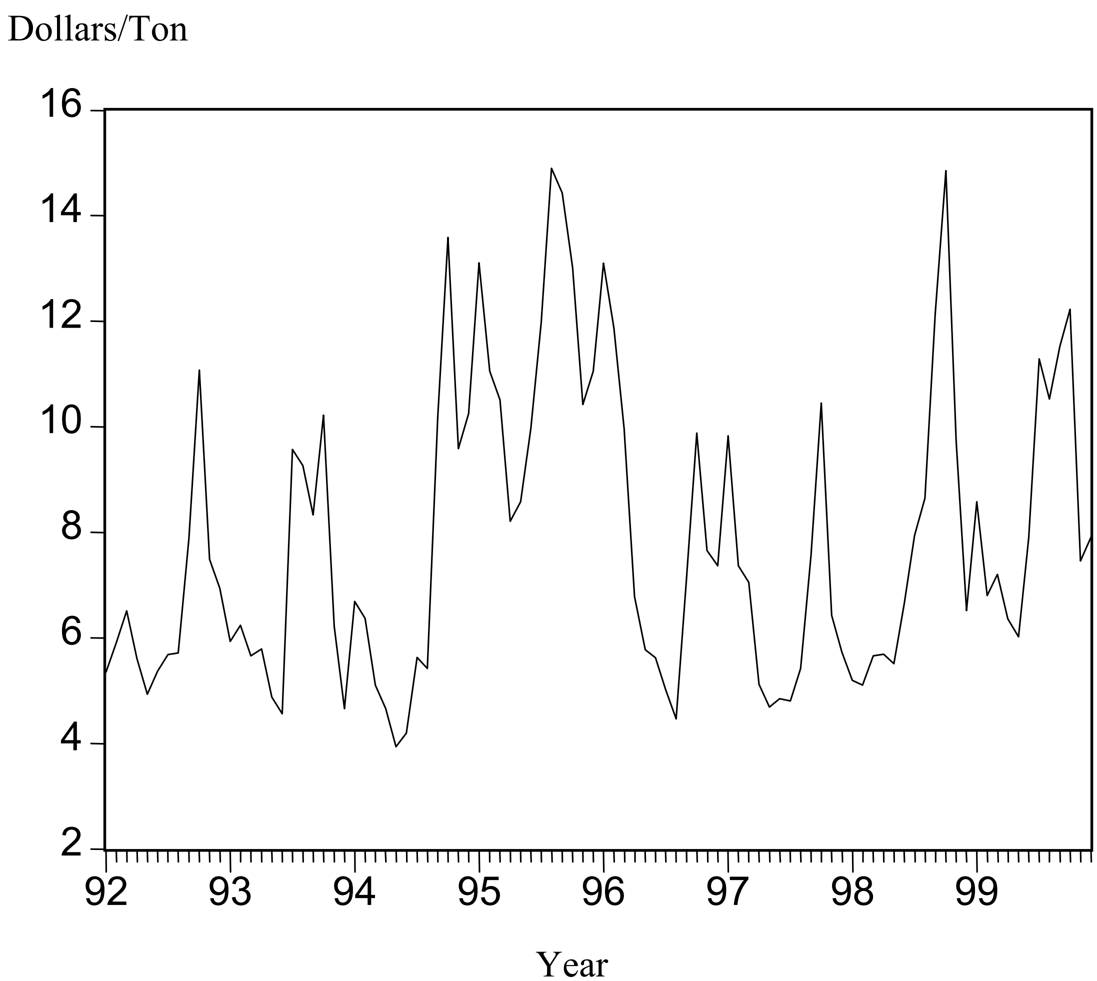



**Figure 4.5. South of Peoria Grain Barge Rate on the Illinois River**

# VITA

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