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A GARCH Approach to Modelling Ocean Grain Freight Rates

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Directed graphs and autoregressive conditional heteroskedastic error processes are used in the specification and estimation of an ocean grain rate equation. Results show voyage distance, ship size, contract terms, flag and season are important explainers of rates, as is ship tonnage contracted for haulage of selected other dry bulk commodities. Findings suggest the importance of efficient port infrastructure and its ability to accommodate the increasingly-large, more efficient bulk carrier in maintaining exporting countries' competitiveness in world grain markets.
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INTRODUCTION

This study empirically examines major factors that affect ocean freight rates for grain, an agricultural commodity whose international transport costs routinely comprise 8% to 20% of the destination market price and whose export value is unequaled for many of the major agricultural trading nations (Jonnala, 1999). Directed graphs and autoregressive conditional heteroskedastic (ARCH) error processes are applied to a time series data set including over 12,000 transactions between international grain traders and ship operators. Directed graphs help specify the estimated rate equation by examining the relationship between ocean grain freight rates and eleven 'possible' explanatory variables.

North America (Canada and the United States) is the principal source of world seaborne trade in grain, originating from 56% to 73% of total world

Table 1: Grain: World seaborne trade in 1998 ('000 tonnes)

From: To:	UK/ Continent	Mediterranean	East Europe	Other Europe	Africa	Americas	Near East	Indian Ocean	Japan	Other Far East	Not specified	Total 1998	Total 1997	Total 1996	Total 1995
United States	5,692	3,909	517	419	11,514	22,538	2,134	4,149	22,656	20,396	52	93,976	100,459	115,420	124,068
Canada	703	911	35	263	3,064	3,763	44	1,635	1,845	3,245	83	15,591	22,458	18,213	18,825
S. America	5,558	3,090	385	968	3,639	10,558	806	2,440	3,333	4,331	–	35,138	30,106	19,802	19,430
Australia	–	438	–	–	2,011	82	93	7,104	1,928	5,983	295	17,934	22,883	18,743	8,336
Others	1,126	2,235	1,705	525	10,491	1,764	1,938	5,449	997	7,147	145	33,522	26,949	20,455	25,505
Total 1998	13,109	10,583	2,642	2,175	30,719	38,705	5,015	20,777	30,759	41,102	575	196,161			
Total 1997	12,613	12,144	2,810	2,289	22,715	31,859	5,828	28,916	31,796	46,322	563		202,855		
Total 1996	11,797	9,522	4,634	2,228	22,745	35,374	5,281	18,845	30,966	50,621	950			192,633	
Total 1995	12,693	12,740	2,502	2,229	26,383	28,870	5,242	15,394	31,373	57,103	1,635				196,164

Note: The term 'grain' comprises wheat, maize, barley, oats, rye, sorghum, and soybeans
Source: Fearnleys *World Bulk Trades 1999*, Oslo, 1999

trade (Table 1). South America ranks second, originating 10% to 18% of world seaborne grain trade, while Australia ranks third. Grain comprises an important share of dry bulk seaborne trade, as does iron ore, coal, bauxite and alumina, and phosphate rock. It is estimated that the majority of the dry bulk shipping market is comprised of these five commodities (Organisation for Economic Co-Operation and Development). Over the 1995 – 1998 period, an average of 1.14 billion tons of coal, iron ore, grain, bauxite and alumina, and phosphate rock were transported in world seaborne trade (Organisation for Economic Co-Operation and Development). Coal and iron ore dominate, with each comprising 36% to 39% of the annual dry bulk trade, while grain (17%), bauxite and alumina (5%), and phosphate rock (2%) comprise the remaining major bulk trades. Interestingly, regions participating in world grain trade also play important roles in other bulk trades. For example, the three major grain exporting regions (North America, South America, and Australia) originate about 60% of world seaborne trade in coal, and bauxite and alumina, and nearly 80% of world seaborne trade in iron ore. In addition, Europe and Asia (Japan in particular) are important importers of grains, coal, iron ore, and bauxite and alumina. The United States, an important exporter of grain, is also an important importer of iron ore, and bauxite and alumina, while the Americas are also important grain importers; thus, a highly interwoven matrix of bulk trade among world trading regions (Organisation for Economic Co-Operation and Development).

Numerous studies have examined some aspect of ocean shipping but few have focused on grain and even fewer on the world grain transportation market and factors which influence rates. De Borger and Nonneman (1981) estimated statistical cost functions for coal, grain, and iron ore carriers operating on selected routes, as did Lundgren (1996). Three studies have focused on ocean grain rates and factors which impact rates. Binkley and Harrer (1981) offer what is perhaps the most comprehensive and definitive analysis. Binkley and Harrer (1981) use 1972 – 1976 international grain charter data (9,356 observations) and ordinary least squares to estimate two rate-dependent linear models. The first model measures the average effect of selected variables on rates, while the second explores issues dealing with economies of scale, and port and at-sea costs. Martin and Clement (1982) closely followed the approach of Binkley and Harrer (1981) in their investigation of ocean grain rates from Lower Columbia River ports in Oregon and Washington. More recently, Hsu and Goodwin (1995) used vector autoregressive (VAR) models to examine dynamic linkages in the ocean grain transport market. Their VAR model contained monthly data on an ocean grain freight rate index, world grain shipments, idle bulk cargo tonnage, new ship deliveries and fuel prices for January 1978 through May 1990.

DETERMINANTS OF OCEAN GRAIN FREIGHT RATES

Lundgren (1996) argues that dry bulk freight rates for the five major bulk trades (iron ore, coal, grain, bauxite and alumina, and phosphate rock) are determined in a world dry bulk freight market, since some portion of the dry bulk carrier fleet can migrate between selected bulk trades when economic incentives exist. To test this view, Lundgren estimated simple correlation coefficients between coal and grain freight rates that link the United States to Europe, and for iron ore rates from Scandinavia and Brazil to Europe for the 1950 to 1993 period, and found correlation coefficients ranging from 0.70 to 0.95. In view of this finding, it seems appropriate to consider whether other bulk trades influence ocean grain freight rates. The following discussion of the various bulk trades and the serving shipping industry is largely based on the writings of Lundgren (1996) and Pirrong (1993).

Although there may be some interchangeability among carriers operating in the various dry bulk trades, there are considerable differences between the dry bulk trades regarding their shipping practices and contract arrangements. Iron ore, the largest of the five major bulk commodity trades, is known as a ‘big ship’ trade (Pirrong, 1993). Stopford (1997) observes that iron ore carriers have gradually increased in size from about 30,000 deadweight tons (dwt) in the early 1960s to 60,000 dwt in 1965; 100,000 dwt in 1969; and more than 150,000 dwt in the early 1970s to near 300,000 dwt in the 1990s. Typically, steelmakers are vertically integrated with specific mines, since the refining process of the steelmaker is tailored to the ore characteristics of these mines. The very large ore carriers contribute to the efficiencies of large steel making operations but they have few uses outside the ore trade; thus, about 90% of the iron ore is shipped under long-term contracts (time charters and contracts of affreightment) that often extend over the productive life of the vessel (Pirrong, 1993). Remaining iron ore moves under voyage charters or short-time charters. The bauxite and alumina trade also involves considerable integration between the aluminum processor and raw material source; however, comparatively modest quantities are shipped as compared to the iron ore trade. Thus, smaller vessels are often used, and there is a reduced tendency to use specialised ore carriers.

Although the coal trade has similarities to the ore trades, there are important differences that resulted from the oil crisis in the late 1970s. Coking coal for steel manufacturing is traded under long-term arrangements and is shipped in moderate-sized general purpose bulkers in the 80,000 – 100,000 dwt range that often operate under time charters of less than three years (Pirrong, 1993). Thermal coal or steam coal trade expanded with the oil crisis in the late 1970s: initially, most steam coal was traded in the spot market and typical carriers were in the 50,000 to 100,000 dwt size category because of port limitations. Most thermal coal was initially transported under voyage charters. However, with maturity in the thermal coal market, more suppliers and utilities have entered into long-term contracts with large bulk carriers, increasingly used when contractual arrangements exist between supplier and buyer.

The international grain trade involves commerce between numerous, geographically-dispersed supply sources and destinations as compared to most bulk commodity trades. Supplies of grain can be obtained in cash markets or *via* forward delivery arrangements from grain merchants operating in North and South America, and Australia. Operators of grain ships know there is a high likelihood of obtaining cargoes at grain ports on the various exporting continents and, accordingly, travel to these ports to obtain loads. Similarly, grain merchants are generally confident that vessels will be available at these port areas. As such, about 60% of the grain is transported under voyage charters with the remainder moving under short-term time charters (Pirrong, 1993). Extended time charters for grain are generally limited to a few very large grain carriers. Further, no unique bulk carrier capabilities are required to transport grain, hence, general purpose tonnage is widely used. Many grain shippers utilise handy-sized vessels (20,000 to 50,000 dwt), while most grain carriage is in vessels which are of the 'Panamax' class (about 80,000 dwt) or smaller (Pirrong, 1993). Pirrong (1993) estimates that over 3,000 vessels were generally available to the international grain trade in early 1993: this is in contrast to the ore trades and to a lesser extent the coal trade where several hundred comparatively large vessels transport much of the commerce.

Previous research suggests other variables must be included in an analysis of factors influencing ocean grain freight rates. Binkley and Harrer (1981) show voyage distance, cargo size, season and shipping terms influence rates. As expected, grain freight rates increase with voyage distance but decline as cargo size, a proxy for ship size, increases. Binkley and Harrer (1981) show grain rates tend to be lowest in the January – March quarter and to increase through the ensuing calendar year to peak in October – December. The free-in-and-out term (FIO) was found to yield the lowest rate since the charterer is responsible for all port loading and unloading charges, while the berth or gross term (BT) was highest because all port costs are the responsibility of the ship owner. The third commonly used shipping term is free discharge (FD). Binkley and Harrer (1981) show that rates associated with the FD term lie between the FIO and BT terms: this is expected since the ship owner is only responsible for port loading charges under the FD term. More recently, Hsu and Goodwin (1995) used a vector autoregressive model containing grain freight rates, grain shipments, idle tonnage, new carrier deliveries and fuel price to evaluate dynamic linkages in the ocean grain freight market. Their results suggest ocean grain rates are largely influenced by factors which shift supply (eg fuel prices) rather than demand-shifting forces.

The objective of this study is to increase the understanding of economic forces that affect international grain freight rates. Directed graph methods, a new area of analysis during the past decade, are used to offer insight on model specification. A GARCH model is estimated that includes ship rates as the dependent variable and explanatory variables that are specified through the use of directed graph methodology.

VARIABLES INCLUDED IN THE STUDY

This section offers a brief discussion of variables which may offer an explanation of ocean grain freight rates. Subsequent to this discussion, a directed graph is used to select continuous variables that will be included in the estimated rate equation.

Variables representing shipment characteristics

Voyage distance, ship size, shipping terms, seasonality, and ship flag were thought to reflect the important characteristics of a contracted haul and are briefly discussed as ‘possible’ explainers of grain freight rates. Table 2 includes descriptive statistics for continuous variables examined in the study.

Voyage distance

Voyage distance (DIST) represents the sea route distance in nautical miles from origin to destination port. Studies by Geraci and Prewo (1977), Binkley and Harrer (1981), and Martin and Clement (1982) show international grain freight rates increase at a decreasing rate as distance of haul increases. To test the effect of distance on grain freight rates, voyage distance (DIST) and the square of voyage distance (DSQ) are included in the analysis (Table 2).

Table 2: Descriptive statistics for continuous variables considered in study

Variable	Mean	Standard Deviation	Minimum	Maximum
RATE ($/metric/ton)	23.91	15.05	5.17	214.35
DIST (nautical miles)	5,937.40	3,043.32	110.00	16,127.00
QUANT (metric tons)	36,745.95	18,600.19	1,100.00	108,664.00
GRAIN (’000 DWT)	3,529.44	916.42	1,730.00	6,132.00
OTHORE (’000 DWT)	107.20	98.48	0.00	485.00
COAL (’000 DWT)	3,391.36	1,496.84	345.00	7,100.00
IRON (’000 DWT)	4,309.40	1,314.25	111.00	8,217.00
FERT (’000 DWT)	355.45	205.83	8.00	1,051.00
OTHAG (’000 DWT)	270.73	134.72	0.00	669.00
FLEET (’000 DWT)	214,802.20	20,093.99	187,206.00	263,300.00
INA (’000 DWT)	4,592.33	1,265.10	2,293.00	8,142.00
FUEL ($/metric ton)	89.60	15.78	65.00	146.00

Shipment quantity or cargo size

The tons of grain shipped in each ship voyage (QUANT) serves as a proxy for ship size. As ship size increases, horsepower and manning requirements increase less than proportionally. Thus, the larger ships with their larger cargoes are expected to have lower at-sea-operating costs per ton of cargo. However, there are conflicting views regarding the effect of ship size on rates, since most believe port costs increase with size of ship. Most studies support Kendall's theory of optimal ship size (1983) which indicate the presence of scale economies over a wide but limited ship size range. To explore the effect of ship size on grain rates, the square of quantity shipped (QSQ) and quantity shipped (QUANT) are examined (Table 2).

Shipping terms

Shipping terms identify obligations of the ship owner and the charterer regarding ship loading and unloading. Commonly used terms in grain shipping are free-in-and-out (FIO), free discharge (FD) and berth or gross terms (BT). The charterer is obligated to cover costs associated with ship loading and unloading under free-in-and-out terms. With the free discharge term, the ship owner pays for loading and the charterer pays for unloading, whereas under the gross or berth term, both loading and unloading costs are borne by the ship owner. Binkley and Harrer (1981) show terms are important in explaining ocean grain rates.

Seasonality

Ocean grain freight rates are expected to be highest in the fourth quarter of the calendar year because of the heightened transport demand that results from crop harvest in the Northern Hemisphere (O'Loughlin, 1967). To capture rate differences resulting from changing shipping demands in each quarter, binary (0 – 1) season variables (DQ_1, DQ_2, DQ_3, and DQ_4) are included in this study.

Flag of the ship

Ships operating under US registry are thought to charge higher rates due to the higher costs of US ship construction and ship operating restrictions. The relationship between a ship's flag of registry and ocean grain rates has been tested by Binkley and Harrer (1981), and Martin and Clement (1982). They show US flag vessels have \$11 to \$50 per metric ton higher rates than foreign flag vessels. To segregate shipments *via* US flag vessels, a binary (0 – 1) variable (FLAG) is incorporated.

Variables representing the demand for shipping services

A measure of demand for ocean grain haulage would appear central to the analysis of ocean grain rates. In view of Lundgren's (1996) argument that there is a globalised dry bulk freight market, data that reflect the demand for other dry bulk carriage are also included here. Grain is primarily transported under voyage charters, while most dry bulk commodities—such as iron ore, other ore, and coal—move primarily in scheduled shipments under time charters. Ships operating under time charters would not generally be available for grain transport; hence, deadweight tonnage of vessels contracted to transport grain and other dry bulk commodities under voyage charters are included in this analysis.

Grain

The deadweight tonnage of bulk carriers chartered per month under a voyage charter to transport grain (GRAIN) was included as a measure of international grain transport demand (Figure 1). An increase in the quantity of grain moving under voyage charters was thought to represent an increase in shipping demand; hence, a positive relationship is expected between rates and chartered grain movements (Table 2). It is assumed that the contracted tonnage is fully utilised.

Coal

The deadweight tonnage of vessels contracted per month to transport coal (COAL) under voyage charters was included as a partial demand for dry bulk shipping service (Figure 2). A positive relationship is expected between tonnage contracted for coal haulage and ocean grain freight rates (Table 2). The positive relationship is based on the assumption that some portion of the dry bulk fleet can migrate between the coal and grain trade, and an increase in tonnage contracted for coal movements yields a corresponding reduction in tonnage available for grain haulage; hence, a positive relationship between tonnage contracted for the coal trade and grain ship rates.

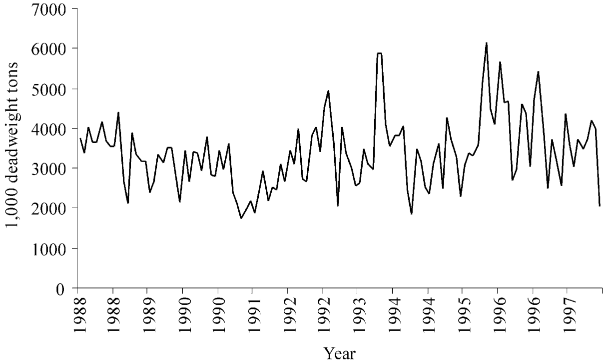

Figure 1: Monthly voyage-chartered tonnage for shipment of grain (1988 – 1997)
Source: Drewry Shipping Consultants Ltd

Iron ore, other ores and other bulk shipments

Deadweight tonnage of dry bulk carriers contracted per month to transport iron ore (IRON), other ores (OTHORE), fertiliser (FERT), and other agricultural products (OTHAG) under voyage charters was also included as a measure of demand for dry bulk carriage. Other ore is primarily bauxite and alumina, but also includes chrome, copper, manganese, zinc, nickel and other ores (Figure 3, Table 2).

Variables representing supply of shipping services

The aggregate deadweight tonnage of active ships comprising the dry bulk fleet was included as representing the supply of shipping service. Since several years are often required to construct a ship, the total supply is comparatively fixed in the short-run. In the long-run, the supply of shipping capacity is determined by new ship deliveries and scrapping of aged vessels. The size of the merchant fleet varies through cycles of expansion and contraction; however, through much of the

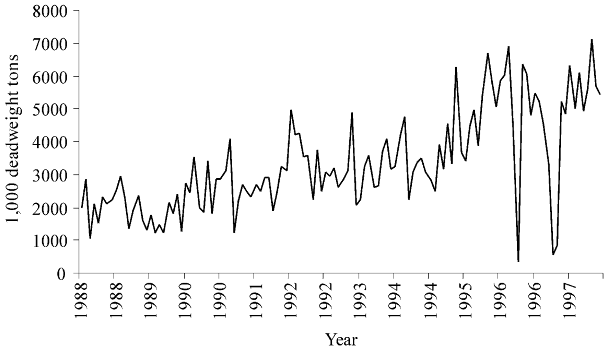

Figure 2: Monthly voyage-chartered tonnage for shipment of coal (1988 – 1997)
Source: Drewry Shipping Consultants Ltd

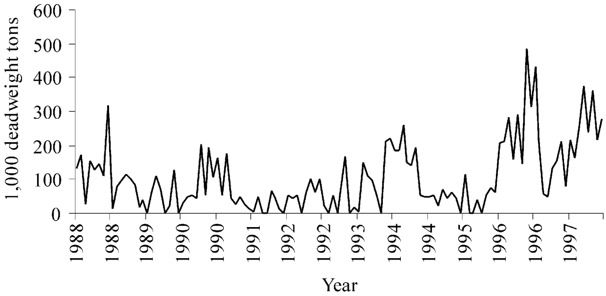

Figure 3: Monthly voyage-chartered tonnage for shipment of other ores (1988 – 1997)
Source: Drewry Shipping Consultants Ltd

1990s, fleet size has increased (Lundgren, 1996). Dry bulk fleet capacity and inactive fleet capacity were considered as potential measures or proxies of dry bulk fleet supply.

Total dry bulk fleet capacity
Total monthly deadweight tonnage of ships comprising the dry bulk fleet (FLEET) was included as a measure of shipping capacity or supply. An increase in the total dry bulk fleet is expected to, ceteris paribus, reduce the freight rate for grain (Table 2).

Inactive fleet capacity
Total inactive fleet capacity (INA) measures total deadweight tonnage of idle and laid-up bulk vessels. Idle dry bulk capacity includes the dry bulk vessels which are undergoing repairs or whose movements have not been reported for two or more months. The laid-up capacity includes the total deadweight tonnage of dry bulk carriers laid-up due to inadequate demand (Table 2). Finally, the price of fuel (FUEL) is included in the analysis (Table 2). As fuel price increases, ships are operated at slower speeds, thus reducing the effective supply of shipping capacity.

Data sources

Ocean grain rate information and associated characteristics of each voyage were obtained from the US Department of Agriculture (USDA), Agricultural Marketing Service, Marketing and Transportation Section. The analysed data series extended from 1988–1997 and included 12,296 observations on grain voyage charters throughout the world. Each observation or contract contained information about time of contract, rate, cargo size, shipment terms, ship flag and ports of origin and destination. Observations were arranged sequentially according to time.

The voyage distance associated with each observation was obtained from a document entitled '*Distances between Ports*' (US Defense Mapping Agency 1985). The distance between origin and destination ports was expressed in nautical miles. Bunker fuel prices are quarterly and were obtained from Bunkerfuels Corporation (1999). Information on forces influencing the supply and demand for grain-shipping services were obtained from Drewry Shipping Consultants Ltd., London, England.

METHOD OF ANALYSIS

In this section, the directed graph analysis is presented and variables included in the estimated rate equation are identified. Next, discussion is offered regarding the estimation of model parameters *via* ordinary least squares and a GARCH model.

Direct graphs

Directed graph methodology is used to identify factors important to the determination of ocean grain freight rates. These newly developed tools emanate from the field of artificial intelligence (Pearl, 2000). An algorithm that allows a computer to define causal flow between or among a set of variables may appear to offer little to economists, as the direction of causal flow is usually defined *a priori*. The derived demand for shipping services depends on (is caused by) the demand for the final product and costs of marketing services, necessary to get the product from point A to point B. And, as the demand for final products is a function of own prices, substitute prices, incomes, and tastes and preferences, the list of possible variables, some of which discussed above, is very long. Further, the supply of shipping services depends on a similarly long list of prices and expected prices (for long-term ship capacity) and costs, as well as prices of competitive products which can contend for space in a fixed capacity setting. Of course, these causal relations are defined under the *ceteris paribus* condition, which holds with unknown force with observational (non-experimental) data. The directed graphs literature is an attempt to infer causal relations from observational data. To the extent that notions of cause go beyond disciplinary bounds and such notions can be defined in terms of a set of coherent conditions, which can be recognised by a computer (or other intelligent agents), these methods are helpful in economics.[1]

While the computer can be helpful in sorting-out causal flows from spurious flows and can sometimes distinguish an effect from a cause, the algorithms require human intervention to select the set of candidate variables upon which they act.

A *directed graph* is a picture representing the causal flow among a set of variables. Arrows are used to represent the direction of causal flow. More formally, it is an ordered triple <V,M,E>, where V is a non-empty set of variables, M is a non-empty set of symbols attached to the end of undirected edges, and E is a set of ordered pairs. Each member of E is called an edge. Variables connected by an edge are said to be adjacent. If we have a set of variables {W, X, Y, Z}: (i) the *undirected graph* contains only undirected edges (eg W – X); (ii) a *directed graph* contains only directed edges (eg $X \rightarrow Y$); and (iii) an inducing path graph contains both directed edges and *bi-directed edges* (the latter defined as edges having arrowheads at each endpoint, eg $Y \leftrightarrow Z$).

We make the assumption that we have a causally sufficient set of variables. That is, we assume that our set of variables does not exclude a variable that is itself the cause of two or more of the variables included in our set (we have no omitted variables). Omitted variables (latent variables) give rise to *partially directed edges* (edges for which we are uncertain whether one endpoint is actually a cause). Latent variable models are given a formal treatment in chapter 6 of Spirtes *et al.* (1993).

A path between variable W and Z is a sequence of edges (W – X – Y – Z). If every edge along a path has an arrowhead that points from the first to the second vertex (variable) of the pair, then we have a directed path ($W \rightarrow X \rightarrow Y \rightarrow Z$). A cyclic path is a directed path that returns to one vertex more than once (eg $X \rightarrow Y \rightarrow Z \rightarrow X$). A directed acyclic graph is a graph that contains no directed cyclic paths. Only acyclic graphs are used in this paper.

Directed acyclic graphs are designs for representing conditional independence as implied by the recursive product decomposition

$$\Pr(v_1, v_2, v_3, \ldots v_n) = \prod_{i=1}^{n} \Pr(v_i \mid pa_i) \qquad (1)$$

where Pr is the probability of variables v_1, v_2, v_3, ... v_n. The symbol pa_i refers to the realisation of some subset of the variables that precede (come before in a causal sense) v_i in order (v_1, v_2, v_3, ... v_n). And the symbol Π refers to the product (multiplication) operator. Pearl (1986) proposes d-separation as a graphical characterisation of conditional independence. Verma and Pearl (1988) offer a proof of this proposition. That is, d-separation characterises the conditional independence relations given by equation (1). If we formulate a directed acyclic graph in which the variables corresponding to pa_i are represented as the parents (direct causes) of V_1, then the independencies implied by equation (1) can be read off the graph using the criterion of d-separation (defined in Pearl, 1995).

Definition: Let X, Y and Z be three disjoint subsets of vertices [variables] in a directed acylic graph G, and let p be any path between a vertex [variable] in X and a vertex [variable] in Y, where by 'path' we mean any succession of edges, regardless of their directions. Z is said to block p, if there is a vertex w on p satisfying one of the following: (i) w has converging arrows along p, and neither w nor any of its descendants are on Z; or (ii) w does not have converging arrows along p, and w is in Z. Further, Z is said to d-separate X from Y on graph G (written as $(X \perp Y \mid Z)_G$, if and only if Z blocks every path from a vertex [variable] in X to a vertex [variable] in Y.

Geiger *et al.* (1990) show that there is a one-to-one correspondence between the set of conditional independencies, $X \perp Y \mid Z$, implied by equation (1) and the set of triples (X, Y, Z) that satisfy the d-separation criterion in graph G. Essential for this connection is the following result: if G is a directed acyclic graph with variable set V, A and B are in V, and H is also in V, then G linearly implies the correlation between A and B conditional on H is zero if and only if A and B are d-separated given H (for details, see Geiger *et al.*, 1990).

Spirtes *et al.* (1993) have used the notion of d-separation in an algorithm for building directed graphs, using the notion of *sepset* (defined below). These logical relationships between cause and effects are programmed into the computer software labeled ‘PC’ algorithm (Scheines *et al.*, 1994).

The algorithm begins with a complete undirected graph in which every variable is connected with every other variable by a line (edge). Lines are then removed sequentially, if the correlation or partial correlation between two variables is not statistically different from zero. Lines not removed are directed after all possible conditional correlations have been considered using the notion of *sepset*. The *sepset* of two variables X and Z is the variable we condition on to remove the line between X and Z. If we remove such a line based on unconditional correlation, the *sepset* is the null set. For example, if there are three variables X, Y, and Z such that $X \rightarrow Y \leftarrow Z$, then Y will not be in the *sepset* of X and Z, and we know the arrows flow from X to Y and Z to Y. On the other hand, if $X \leftarrow Y \rightarrow Z$, then Y is in the *sepset* of X and Z (Y is a common cause of X and Z); then, we know the arrows cannot flow inward, as above. Details are given in Spirtes *et al.* (1993).

Of course, removal of lines based on zero correlation or partial correlation requires hypothesis testing when the algorithm is applied with real-world data. PC algorithm assumes normality and thus applies Fisher’s Z-statistic for the calculation of p-values on each correlation or partial correlation (see Sprites *et al.*, 1993).

The results from application of the PC algorithm applied at a 5% significance level showed voyage distance (DIST), shipment quantity (QUANT) or cargo size, tonnage of voyage-chartered carriers contracted for transport of other ore (OTHORE) and coal (COAL) were important in explaining variation in ocean grain freight rates (Figure 4). Hence, these variables along with the binary variables that measure seasonality, shipping terms and flag of registry were included in the model.

Ordinary least squares estimates

The econometric software, Econometric Views (Eviews), was used for model estimation and conducting statistical tests. The ocean grain rate model was initially estimated by ordinary least squares. The dependent variable, ocean grain rate was regressed against voyage distance (DIST), shipment quantity (QUANT) or cargo size, seasonal dummies for quarters (DQ_1, DQ_2, DQ_3, DQ_4), binary variables to represent shipping terms (DFD, DBT, DFIO), a dummy to represent US flag of registry (FLAG), deadweight tonnage of bulk carriers involved in voyage-chartered shipments of other ore (OTHORE), deadweight tonnage of bulk carriers involved in voyage-chartered shipments of coal (COAL), voyage distance squared (DSQ) and the square of cargo size or quantity shipped (QSQ). The model was estimated with the first 12,000 observations from the 1988 – 1997 data set.

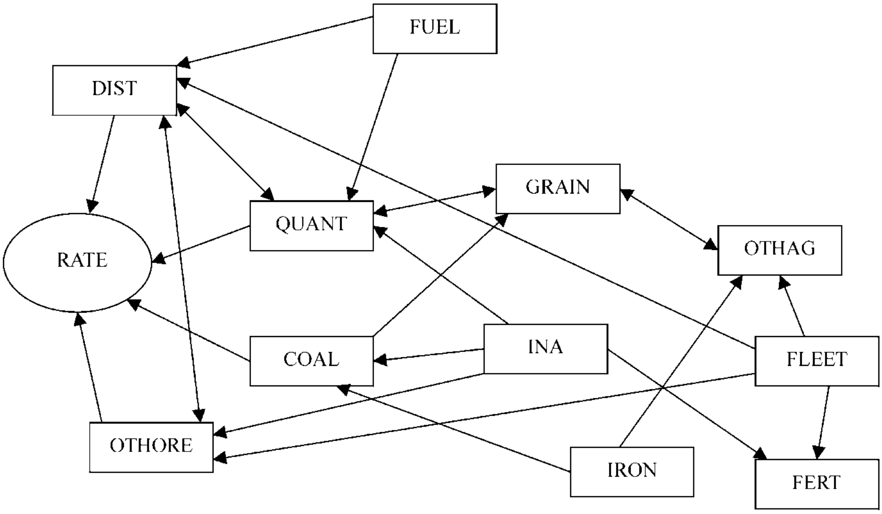

Figure 4: Directional relationships between variables considered in the study

A Durbin – Watson statistic of 1.52 was estimated, thus suggesting the presence of positive autocorrelation in the residuals (Durbin and Watson, 1971). To improve the value of the Durbin – Watson statistic, Granger and Newbold (1986) suggest including the lag of the dependent variable (LAGRATE) as an explanatory variable.

The White test (White, 1980) indicated the presence of heteroskedasticity. A plot of residuals against the independent variable (Figure 5), shipment quantity (QUANT) or cargo size, showed variance to be decreasing as quantity shipped increased, an expected relationship. A plot of the residuals indicated the size of the residual was related to the size of the previous residual. This suggested autoregressive conditional heteroskedasticity (ARCH). The residuals were checked for the presence of ARCH effects with the Lagrange Multiplier (LM) test (Engle, 1982). This showed the presence of autoregressive conditional heteroskedasticity when estimated *via* ordinary least squares.

The autoregressive conditional heteroskedasticity (ARCH) model introduced by Engle (1982) allows variance of a regression to change over time. This analysis indicated an ARCH model may resolve the statistical problems associated with the ordinary least squares estimates.

GARCH model estimates

In developing an ARCH model, two distinct specifications are considered. One specification for the conditional mean and the other for the conditional variance.

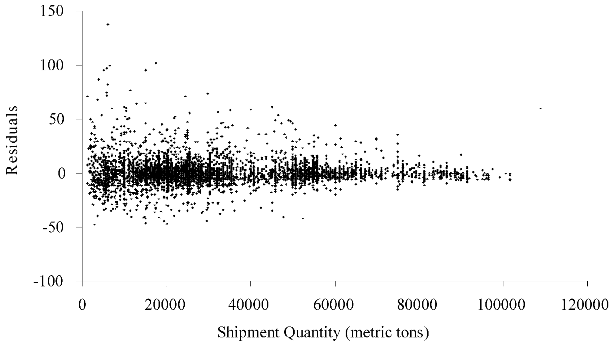

Figure 5: Plot of the residuals associated with Ordinary Least Squares Equation *versus* the shipment quantity variables

With an ARCH model, a relatively long lag in the conditional variance equation is often required. To avoid problems with negative variance parameter estimates, a fixed lag structure is typically imposed. An extension of ARCH models, the generalised autoregressive conditional heteroskedasticity (GARCH) models introduced by Bollerslev (1986) allow for both long memory and a more flexible lag structure. Thus, the GARCH methodology appeared to be most appropriate for the present study.

The GARCH model is estimated by the maximum likelihood method. Since variance appears in a non-linear manner in the likelihood function, the likelihood function must be estimated by an iterative procedure that involves calculating the constant term and then the coefficients. The iterative procedure converges by carrying out three steps on the constant term and three steps on the coefficients, followed by three more steps on the constant term and so forth. Convergence occurs when the difference between two sets of constant terms and coefficients are within 0.1% of the final value (Engle, 1995).

The dependent variable, ocean freight rate for grain (RATE) was regressed on the specified independent variables by including one ARCH and one GARCH term. The lag of the dependent variable (LAGRATE) was included as an explanatory variable to reduce autocorrelation.

The estimated model explains 69% of the variation in ocean grain freight rates. The goodness-of-fit, as measured by the adjusted R^2, improved from 68% when estimated with ordinary least squares to 69% when estimated with GARCH (Table 3). Ten of the 14 estimated parameters are significant at the 0.01 level, one parameter at the 0.05 level, and two parameters at the 0.10 level. Only one dummy variable (DQ_3) was not statistically significant at usual levels. The standard errors of the parameter estimates are smaller for the GARCH model as

Table 3: Parameter estimates and standard errors for GARCH model

Variable	Parameter Estimate	Standard Error
CONSTANT	16.03*	$7.15*10^{-1}$
DIST	$3.73*10^{-3*}$	$5.47*10^{-5}$
QUANT	$-5.61*10^{-4*}$	$1.02*10^{-5}$
OTHORE	$-1.07*10^{-2*}$	$1.91*10^{-3}$
COAL	$1.94*10^{-4***}$	$1.38*10^{-4}$
DQ1	$7.74*10^{-1***}$	$5.18*10^{-1}$
DQ2	1.34**	$4.61*10^{-1}$
DQ3	$-1.63*10^{-1}$	$4.11*10^{-1}$
DFD	11.37*	$4.02*10^{-1}$
DBT	22.49*	$4.62*10^{-1}$
FLAG	21.98*	$4.11*10^{-1}$
DSQ	$-1.25*10^{-7*}$	$1.63*10^{-9}$
QSQ	$3.89*10^{-9*}$	$2.24*10^{-10}$
LAGRATE	$8.71*10^{-2*}$	$9.34*10^{-3}$
R-squared	0.69	
Adjusted R-squared	0.69	
S.E. of estimated rate	8.45	
F-statistic	1638.92	
DW-statistic	1.72	

Notes: *Statistically significant at 0.01 level
**Statistically significant at 0.05 level
***Statistically significant at 0.10 level

compared to the ordinary least squares model. The Durbin – Watson test statistic also improved from 1.52 to 1.72; this suggested autocorrelation was no longer a problem. Results from the Lagrange Multiplier (LM) test indicated there were no ARCH effects within the first order or second order residuals obtained from the GARCH model.

RESULTS

Discussion is offered for each of the variables included in the estimated rate equation (Table 3).

Voyage distance

The parameter estimates obtained for both the linear and quadratic distance terms are statistically significant at the 0.01% level, indicating distance of haul is an important explainer of ocean grain rates (Table 3). As expected, the coefficient on the DIST variable is positive and it shows a 1,000 nautical mile increase in voyage distance will increase the grain freight rate by $3.73 per metric ton. The square of the distance variable (DSQ) is negative, indicating a quadratic relationship between ocean freight rates and distance of haul. At the means, the voyage distance elasticity is estimated to be 0.56, ie a 1% increase in voyage distance increases ocean freight rates 0.56%. The maximum point on the distance parabola was 14,924 nautical miles, which is approximately one-half the distance around the world. This result has intuitive appeal, since a destination could be more easily reached by traveling in the opposite direction. Martin and Clement (1982) obtained a corresponding value of 11,950 miles.

Shipment quantity or cargo size

The coefficients obtained on shipment quantity (QUANT) or cargo size and the square of shipment quantity (QSQ) were highly significant (0.01 level), indicating the importance of shipment quantity, a proxy for ship size, in explaining grain freight rates (Table 3). The cargo size elasticity at the means is estimated to be −0.85; thus, a 1% increase in cargo size lowers the estimated rate by 0.85%. The estimated coefficient shows a 1,000 metric ton increase in cargo size will decrease the ocean grain rate by $0.561 per metric ton. The coefficients on the cargo size and squared cargo size variables suggest economies of ship size over a large but not unlimited range. The cargo size parabola was found to reach a minimum at 72,108 metric tons. Binkley and Harrer (1981) obtained a corresponding value of 50,000 metric tons.

Voyage-chartered shipments of other ore

The deadweight tonnage of voyage-chartered bulk carriers involved in the transport of other ores (OTHORE) was found statistically significant at the 1% level (Table 3). However, the hypothesised positive relationship between voyage-chartered tonnage contracted for transport of other ore and the ocean grain rate was not supported by the results. The negative coefficient suggests the freight rate for grain decreases by $0.011 or 1.10 cents per metric ton when the voyage-chartered tonnage involved in transport of other ore increases by 1,000 deadweight tons. The corresponding elasticity at the means is estimated to be −0.05.

A possible explanation for the negative relationship between voyage-chartered transportation of other ore and ocean grain rates centres on increased grain backhaul opportunities. Other ore shipments (OTHORE) are primarily bauxite and alumina with European and North American countries the leading importers of these products (Organisation for Economic Co-Operation and Development). It is hypothesised that an increase in voyage-chartered shipments of other ore to North America would increase the number of empty bulk carriers seeking a back-haul from North American ports. And, this increase in dry bulk shipping capacity at North American ports (source of two-thirds of world grain exports) would decrease the ocean grain rate for North American grain exports. Thus, a possible explanation for the negative relationship between ocean grain rates and voyage-chartered tonnage contracted for the transport of other ore.

Voyage-chartered shipments of coal

The coefficient obtained on the voyage-chartered tonnage contracted for coal transport (COAL) was positive, as expected, and statistically significant at the 10% level (Table 3). Increasing voyage-chartered tonnage for coal transport by 1,000 deadweight tons increases the ocean grain rate $0.0002 or 0.02 cents per metric ton or $0.20 per 1,000 metric tons of grain. The corresponding elasticity at the means is estimated to be 0.03, ie a 1% increase in voyage-chartered tonnage for coal transport increases grain freight rates by 0.03%.

Seasonality

Quarterly dummy variables (DQ_1, DQ_2, DQ_3, and DQ_4) were included in the specified model to measure possible seasonality in ocean grain rates. The fourth quarter (DQ_4) is included as the base (Table 3). The coefficients for DQ_1 and DQ_2 are positive and significantly different from zero at the 10% and 5% significance levels, respectively. The estimated coefficients indicate the freight rates for grain in the first and second quarter are higher by $0.774 and $1.34 per metric ton, respectively, as compared to the freight rates in the fourth or the base quarter, while rates in the third quarter are lower than the fourth quarter by $1.63 per metric ton. Thus, there is seasonality in ocean grain rates with highest rates in the second quarter and lowest rates in the third quarter. This outcome was unexpected, since ocean grain rates were thought to be highest in the fourth quarter as a result of the Northern Hemisphere harvest. The comparatively high rates in the second quarter may be due to the increased aggregate demand for bulk shipping services in the second quarter. The amount of grain and other dry bulk tonnage contracted for transport of iron ore, other ore, coal, and other agricultural products under voyage-charters tends to be greatest in May and June; hence, a possible explanation for higher freight rates for grain in the second quarter. Further, Southern Hemisphere countries often harvest grain during the second quarter, and because of inadequate storage capacity they tend to export large quantities during harvest, thus placing possible upward pressure on ocean grain rates during this time period. Lence (2000) points out that Argentina ships about two-thirds of its annual corn exports in a four month time span (including the second quarter) covering both a harvest and a post-harvest period, while the US's monthly exports of corn comprise from 7% to 9% of annual shipments.

Shipping terms

Shipping terms are included as binary variables (DFD, DBT, and DFIO) in the specified model. The free-in-and-out (DFIO) term serves as the base. Results indicate the free discharge (DFD) and berth terms (DBT) are statistically significant in explaining ocean grain rates. As expected, the coefficients on DFD and DBT are positive, indicating rates under free discharge and berth terms are higher than rates under the free-in-and-out term. The coefficient on the free discharge (DFD) term shows the freight rate for grain is increased by \$11.37 per metric ton if the ship owner is responsible for ship loading, while the coefficient on the berth term (DBT) indicates rates are about \$22.49 per metric ton higher if the ship owner is responsible for both ship loading and unloading (Table 3).

Flag of the ship

The binary variable used to differentiate US flag vessels (FLAG) is highly significant in explaining ocean freight rates for grain. Results show rates of US flag vessels average \$21.98 per metric ton higher than foreign flag vessel rates (Table 3).

Lagged rate

The lagged dependent variable (LAGRATE) was included in the empirical model to reduce autocorrelation (Granger and Newbold, 1986). The LAGRATE variable was highly significant in explaining the ocean freight rate for grain. The coefficient on LAGRATE was positive implying that a \$ 1,00 per metric ton increase in the prior period rate would increase the current period rate by \$0.087 per metric ton (Table 3).

Model predictions

The empirical model was tested for its forecasting ability, as the practical purpose of constructing an empirical model is to forecast future events. A reliable freight rate forecasting model would aid grain traders in planning grain shipments, and ship owners in making decisions regarding chartering, timing of repairs and laying-up and scrapping of ships. The model was fitted to the first 12,000 observations and then used in obtaining out-of-sample forecasts for the remaining 296 observations. The forecasting accuracy of the estimated model was compared with a random walk model, where the best forecast for the current freight rate is the prior period's freight rate.

A random walk model is given by:

$$y_t = y_{t-1} + \varepsilon_t \tag{2}$$

with $E(\varepsilon_t) = 0$ and $E(\varepsilon_t\ \varepsilon_s) = 0$ for $t \neq s$

The one-step ahead forecast for such a random walk process is given by:

$$\hat{y}_{t+1} = y_t + E(\varepsilon_{t+1}) = y_t \tag{3}$$

The out-of-sample forecasts were obtained from both models and then compared. The plot forecasts from the random walk model and the estimated model are contrasted with the actual freight rate for grain in Figures 6 and 7.

The ratio between the estimated rate and actual rate for the estimated model was closer to one than the ratio associated with the random walk model,

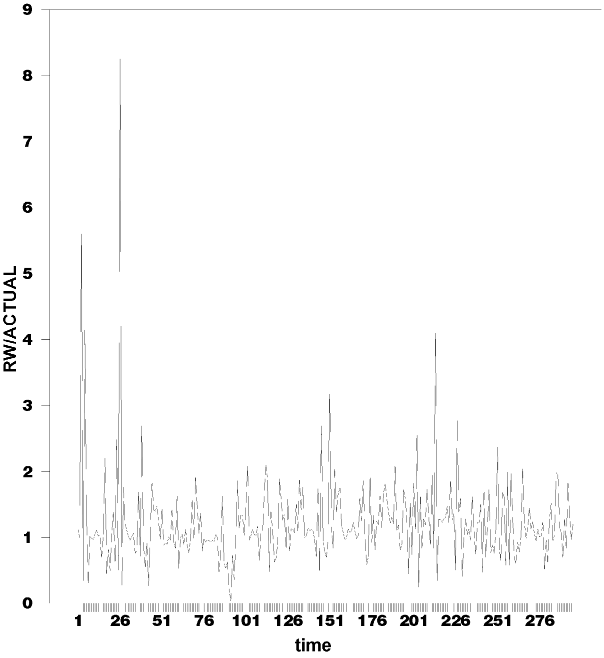

Figure 6: Forecasts of the random walk divided by the actual

indicating the estimated model was superior to the random walk model for purposes of prediction. The calculated root mean squared error (RMSE) for the random walk model was 16.27 while the RMSE for the fitted empirical model was 6.83. The comparatively small RMSE associated with the estimated model suggests its potential use as a reliable forecasting model for the grain trade and shipping community.

CONCLUSIONS

North American grain producers (Canada and United States) dominate the world grain trade, accounting for 56% to 73% of seaborne grain shipments in recent years. Efficiencies in grain production, marketing and transportation are central to these regions' competitiveness in world grain markets. This study focuses on ocean grain rates, a barrier to international grain trade that may surpass grain tariffs and other institutional constraints.

As expected, results show voyage distance and carrier size to have an important influence on ocean grain rates with respective elasticities of 0.56 and

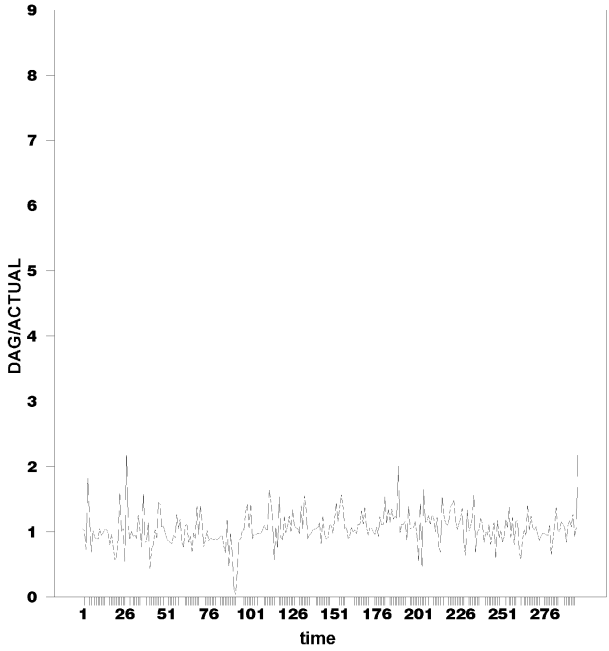

Figure 7: Forecast of the DAG model divided by the actual

-0.85 at their mean values. Results support Kendall's (1983) view that economies of grain ship size are bounded, ie there is a least-cost or optimal ship size because of higher port costs associated with larger vessels. This study shows bulk carriers that accommodate grain cargoes of 72,000 tons to be least-cost while an earlier study (Binkley and Harrer, 1981), based on early 1970's data, showed carriers that accommodated a 50,000 ton cargo to be optimal. This finding supports the view that least-cost grain carrier size has increased over time. These studies suggest least-cost grain carrier size has increased about 45% over a 20 year time period. In addition, this study evaluated Lundgren's (1996) argument that bulk carrier rates are determined in an international dry bulk freight market because of the interchangeability of some carriers among the various dry bulk trades. Results show voyage-chartered tonnage entering into the haulage of coal and other ores impacts upon ocean grain rates; however, the effect is comparatively modest. In particular, a 1% increase in tonnage contracted for coal and other ore movements yield a 0.05% and -0.03% change in ocean grain rates, respectively. The unexpected negative sign on the other ores variable was thought to result from increased tonnage available for grain backhauls from North American ports. Study results also show the presence of seasonality in ocean freight rates, with highest rates in the second quarter and lowest rates in the third quarter. In addition, contract terms are important in explaining rates and results suggest port costs associated with grain carrier loading and unloading to be quite large.

Finally, study results indicate some forces that influence ocean grain rates are unalterable (eg voyage distance); however, important rate-altering forces can be affected. In particular, the high port costs associated with the contract terms variables and the effects of larger carriers on ocean grain rates suggest the importance of efficient port infrastructure and its ability to accommodate the increasingly-large, more efficient bulk carriers. Efficiently servicing the larger, more efficient bulk carrier appears central to maintaining exporting countries' competitiveness in world grain markets.

ENDNOTES

[1] This is not the place to elaborate on the relationship between directed graphs, causation, and experimental design. Spirtes *et al.* (1999) show the connection between directed graphs and the counterfactual variable model (the random assignment experimental model) of Rubin (1978). In particular, the counterfactual results of Rubin, for a causally sufficient set of variables, can be rigorously derived from the Markov, Faithfulness and Manipulation conditions basic to the directed graphs literature. Causal sufficiency, the condition that one has identified all of the common causes for any two or more of the variables, suggests that he/she possesses considerable amount of subject matter (substantive) knowledge (Hausman and Woodward, 1990).

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