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Demand Analysis for Coal on the United States Inland Waterway System: Fully-Modified Cointegration (FM-OLS) Approach

by Junwook Chi and Jungho Baek

The Phillip-Hansen fully-modified cointegration (FM-OLS) approach is applied to examine the dynamic relationship between demand for coal barge transportation, and explanatory variables such as barge and rail rates, domestic coal consumption and production, and coal exports. The results provide strong evidence that there exists a long-run equilibrium relationship between demand for coal barge transportation and the selected variables. It is also found that, in the long-run, the domestic coal consumption and coal exports are more important than other variables in determining the demand for coal barge transportation. In the short run, on the other hand, domestic coal production is found to be the only significant determinant of coal demand. This dynamic analysis will shed new light on the dynamic interrelationships between the demand for coal barge transportation and its major determinants, and contribute to the empirical literature on transportation economics.

INTRODUCTION

The United States inland waterways consist of over 12,000 miles of navigable waters, including the Mississippi, the Ohio River Basin, the Gulf Intercoastal Waterway, and the Pacific Coast systems (Clark et al. 2005). The inland waterway system plays a crucial role in supporting the nation's movements of bulk commodities and raw materials, and barge carriers provide economically sound and efficient services. In 2007, for example, the inland waterway system transported 403 million tons and 157 billion ton-miles of commodities (Bureau of Transportation Statistics 2007). Based on low transportation costs, such large amounts of freight have long served to increase business and economic activities, thereby contributing to regional economic development.

In the literature on transportation economics, a number of studies have been conducted to examine demand for freight transportation on the inland waterway system and to evaluate the determinants of barge traffic systems. One branch of literature relates to analyses of barge demand and grain movements forecasts (Tang 2001, Babcock and Lu 2002, Thoma and Wilson 2004a, Yu and Fuller 2005, DeVuyst et al. 2009). For example, Tang (2001) uses an autoregressive integrated moving average (ARIMA) model to forecast soybean and wheat tonnage on the McClellan-Kerr Arkansas River Navigation System; the results show small differences between the actual and forecasted soybean and wheat tonnage (less than 10%). Thoma and Wilson (2004a) adopt a vector error-correction (VEC) model to forecast annual tonnages on the Mississippi River; they find that the annual growth rates for the upper, mid, and lower Mississippi River segments range from 1.45% to 3.33% (1.68% as a whole). DeVuyst et al. (2009) employ a spatial optimization model to forecast grain flows on the Mississippi River; they provide evidence that longer-term projections have much larger errors, due mainly to uncertainty.

Another group of studies focuses on transportation rates on the inland waterway system (Harnish and Dunn 1996, Miljkovic et al. 2000, Thoma and Wilson 2004b, Yu et al. 2007, Babcock and Fuller 2007). For example, Harnish and Dunn (1996) use a reduced-form equation to examine the factors determining grain barge rates on the Mississippi River; they conclude that in the short run, grain exports, coal barge rates, input costs, and distance are the key determinants of barge rates on the Mississippi River. Thoma and Wilson (2004b) employ a vector autoregressive (VAR) model to characterize short-run grain movements on the Mississippi and Illinois Rivers; they show that barge rates are significantly determined by lockages and rail rates. Babcock and Fuller (2007) estimate demand for corn and soybean shipment on the Ohio River using OLS; they show that corn and soybean shipments in the region are mainly determined by lagged shipments, corn and soybean stocks, and exports.

Until recently, however, empirical studies have mostly concentrated on assessment of the demand for *grain* barge transportation and barge rates to identify factors affecting grain movements by barge, as well as barge demand and grain movement forecasts. Accordingly, little attention has been paid to the factors affecting *coal* shipments and the substitution effect between water and rail carriers for coal shipments.[1] Given that coal is one of the primary commodities on the inland waterway system, it is important to fully understand the determinants of demand for coal barge transportation. In 2009, for example, coal accounts for approximately 24% of total commodities shipped on the inland waterway system in the United States (U.S. Army Corps of Engineers 2010). Particularly, coal is the highest traffic volume moving within and through the Ohio River Basin because of the substantial amount of reserves in the region (Clark et al. 2005); in 2008, barge delivered 123 of the 744 coal movements, representing 16.5% of the total movements (U.S. Energy Information Administration 2010). Another important point frequently overlooked in the literature is that although some analysts use time-series data/methods (Harnish and Dunn 1996, Miljkovic et al. 2000, Yu and Fuller 2005), they tend to take little cognizance of the unit root problems associated with level variables. In other words, those studies use the level of each variable in their regression analysis without taking into account the non-stationarity in the data. When data are not stationary, standard critical values used in determining the significance of estimated coefficients are not valid (Wooldridge 2006).[2] Finally, the earlier studies have concentrated on the short-run movements on the inland waterway system (Tang 2001, Babcock and Lu 2002, Thoma and Wilson 2004b). Since the short-run effects of barge transportation and barge rates could be different from the long-run effects, it is important to include the long-run dynamics in a model.

This paper has attempted to expand the scope of previous work by assessing determinants of demand for coal barge transportation in a dynamic framework of cointegration. The empirical focus is on identifying the dynamic effects of transport rates–such as barge and rail rates, coal production, coal consumption, and coal exports–on the quantity of coal shipped by barge. For this purpose, a fully-modified cointegration (FM-OLS) technique developed by Phillips and Hansen (1990) is used. The FM-OLS method is a convenient tool to examine dynamic interactions when variables used in the model are non-stationary $I(1)$ processes. In addition, the FM-OLS is less sensitive to changes in lag structure and performs better for small or finite sample sizes than other cointegration techniques (Engle and Granger 1987, Johansen 1988). This dynamic analysis could enhance the understanding of demand for coal barge transportation on the U.S. inland waterway system and provide vitally important information for policymakers and shippers. From a policymaker's perspective, it is essential to understand the determinants of coal movements to build adequate regional planning and port capacity. Appropriate planning and investment for the inland waterway system can increase the capacity of the waterway system and efficiency of barge movements, and can reduce the time and costs of coal shipments. From a shipper's perspective, on the other hand, it is necessary to assess transportation equipment needs and to develop business plans. Shippers can make labor and capital investment plans based on the determining factors for coal shipments.

The remainder of the paper is organized as follows. The next section develops an empirical model, with a discussion of the equation being estimated, the FM-OLS approach, and data description. The third section presents the empirical results, focusing on key determinants for coal barge movements and the implications of the results. The last section summarizes the paper with concluding remarks.

EMPIRICAL METHODOLOGY

Equation to be Estimated

The demand for barge transportation is typically derived from the demand for commodities in origin and destination regions, known as a derived demand. The demand for coal barge service, for example, is determined by factors shifting the supply curve in coal production regions and demand curve in coal consumption markets (Boyer 1997). If the coal production in origin regions or the coal consumption at destination markets increases, the demand for coal barge service tends to increase.

In analyzing factors affecting demand for barge transportation in an empirical work, this paper relies on a theoretical framework developed by Tang (2001) and Yu and Fuller (2005). In its general form this model specifies the demand for barge service as a function of the supply (production) of a commodity at origin, the demand (consumption) for a commodity at destination, and price and service characteristics of barge and competing transportation mode (e.g., barge and rail rates) (see Tang [2001] for an extensive discussion of the demand for barge transportation). In the empirical model used here, the standard demand model of barge service is modified in order to examine factors affecting coal barge demand. The reduced-form equation for the quantity of coal transportation service (TV_t) is specified as follows:

$$(1)\quad TV_t = f(BR_t, EX_t, DD_t, DS_t, OT_t)$$

where BR_t is the coal barge rate; EX_t is the coal export level; DD_t is the domestic consumption of coal; DS_t is the domestic production of coal; OT_t is the rate proxy of other transportation modes. As noted earlier, for the competing transportation mode for coal shipment, rail transportation is considered as a possible substitute of barge service for coal.[3]

To illustrate the FM-OLS modeling approach, Equation (1) is then expressed in a log linear form as follows:

$$(2)\quad \ln(TV_t) = \alpha + \beta_1 \ln(BR_t) + \beta_2 \ln(EX_t) + \beta_3 \ln(DD_t) + \beta_4 \ln(DS_t) + \beta_5 \ln(OT_t) + \varepsilon_t$$

Since an increase in the barge transport rate tends to reduce the quantity of coal shipped by barge, it is expected that $\beta_1 < 0$. An increase in coal exports and domestic consumption leads to an increase in demand for coal; hence, it is expected that $\beta_2 > 0$ and $\beta_3 > 0$, respectively. Because an increase in the production of coal from coal mines causes an increase in coal demand for barge service, it is expected that $\beta_4 > 0$. Unlike the four variables, the expected sign of rail rates is ambiguous and uncertain. In general, water and rail services are considered as substitutes for freight shipments in long hauls, suggesting that an increase in rail rates can be positively associated with barge freight volume. However, the substitutability between water and rail services depends on many factors, such as the type of commodities, the location of origin and destination, and the availability of loading/unloading and switching facilities. If a rail service is not physically available or economically viable for the coal barge movements, a shift in rail rates may not lead to a change in the quantity of coal for barge service (i.e., independent service). As such, the expected sign of the rail rate in Equation (2) is not predetermined, due mainly to insufficient information on the substitutability between these two modes for coal shipments.[4]

The FM-OLS Approach

The fully-modified cointegration (FM-OLS) method developed by Phillips and Hansen (1990) is used to examine factors affecting coal barge demand. The FM-OLS model is an alternative dynamic model to obtain an unbiased estimate of the long-run relationship when the underlying regressors are nonstationary *I(1)* processes.[5] Note that, unlike OLS, the FM-OLS approach does not require differencing of nonstationary variables to make them stationary; hence, this method keeps valuable information concerning long-run properties inherent in the levels of time-series data (Perman 1991). The FM-OLS uses an econometric model as follows:

$$(3) \quad y_t = \alpha + \beta_1' x_t + \varepsilon_t$$

where y_t is $I(1)$ variable (in this paper, $y_t = TV_t$, where TV_t is the quantity of coal transportation service); and x_t is $(k \times 1)$ vector of $I(1)$ regressors (i.e., $x_t = BR_t, EX_t, DD_t, DS_t, OT_t$ where BR_t is the coal barge rate; EX_t is the coal export level; DD_t is the domestic consumption of coal; DS_t is the domestic production of coal; OT_t is the rate proxy of other transportation modes), which are assumed not to be cointegrated among themselves. Additionally, x_t is assumed to have the following first-difference stationary process:

$$(4) \quad \Delta x_t = \mu + v_t$$

where μ is $(k \times 1)$ vector of drift parameters;[6] v_t is $(k \times 1)$ vector of $I(0)$, or stationary variables. It is also assumed that $\xi_t = (\varepsilon_t, v_t')'$ is strictly stationary with zero mean and a finite positive-definite covariance matrix, Σ.

The OLS estimators of α and β_1' in Equation (3) are consistent even if x_t and ε_t (equivalently v_t and ε_t) are contemporaneously correlated (Engle and Granger 1987; Stock 1987).[7] In general, however, the OLS regression involving non-stationary variables no longer provides the valid interpretations of the standard statistics such as t- and F-statistics in Equation (3). Further, unless non-stationary variables combine with other non-stationary variables to form stationary cointegration relationships, the estimation can falsely represent the existence of a meaningful economic relationship (i.e., spurious regression) (Harris and Sollis 2003). To address these problems adequately, it is necessary to correct the possible correlation between v_t and ε_t , and their lagged values. The Phillips-Hansen FM-OLS estimator takes account of these correlations in a semi-parametric manner. As a result, the FM-OLS is an optimal single-equation technique for estimating with $I(1)$ variables (Phillips and Loretan 1991).

It is worth mentioning that the non-stationarity of time-series data can be first-differenced rather than in levels in a framework of OLS. First-difference, however, may lose valuable information concerning long-run properties inherent in the levels of time-series data (Perman 1991). Therefore, with the long-run information embedded in the levels data the cointegration approach (i.e., FM-OLS) offers a solution to this dilemma.

Data

The U.S. Department of Energy (DOE) is the primary data source for this paper. The coal domestic tonnages by barge (measured in million tons) are obtained from *Coal Transportation: Rates and Trends in the United States* (U.S. Energy Information Administration 2004). Domestic coal consumption, production, and exports (measured in million tons) are taken from the EIA. Average barge and rail rates (measured in U.S. $ per ton) are also collected from the EIA, which are originally complied by the Federal Energy Regulatory Commission (FERC).[8] The GDP deflator (2000=100) is used to derive real barge and rail rates. The data set contains 23 annual observations for the period 1979 to 2001. All variables are in natural logarithms.

It should be pointed out that the 1979-2001 period is currently the best data available for the analysis as the EIA has not yet updated the relevant dataset.[9] For this reason, the sample size could be a concern for validation of the dynamic relationships estimated by our empirical model; the findings should thus be viewed with caution. As Hargreaves (1994) notes, however, the FM-OLS procedure has been proven to have superior small sample properties, which makes it a good choice for our sample than other cointegration techniques (e.g., Engle and Granger 1987, Johansen 1988); this should mitigate the concern with the relatively short period of data coverage and provide credibility of our findings.

EMPIRICAL RESULTS

The first requirement for application of the FM-OLS cointegration procedure is that the variables in Equation (2) must be non-stationary with $I(1)$ processes. The presence of a unit root in the six variables is determined using the Dickey-Fuller generalized least squares (DF-GLS) test (Elliot et al. 1996). The DF-GLS test optimizes the power of the ADF test using a form of detrending. As Elliott et al. (1996, p. 813) note: "Monte Carlo experiments indicate that the DF-GLS works well in small samples and has substantially improved power when an unknown mean or trend is present." Recently, Ng and Perron (2001) produced a testing procedure which incorporates both the new information criterion for setting the lag length and GLS detrending. The results show that, with the level series, the null hypothesis of non-stationarity cannot be rejected for all six variables at the 5% level (Table 1). With the first-differenced series, on the other hand, all the variables are found to be stationary; hence, this analysis concludes that all the variables are non-stationary $I(1)$ processes. The DF-GLS test statistics are estimated from a model that includes a constant and a trend variable. The lag lengths are selected using Schwarz criterion (SC).

Table 1: Results of Unit Root Test[a]

Variable	Level	First difference	Decision
$\ln(TV_t)$	-1.910 (1)	-5.701* (0)	$I(1)$
$\ln(BR_t)$	-2.516 (0)	-4.960* (0)	$I(1)$
$\ln(EX_t)$	-2.405 (0)	-3.941** (0)	$I(1)$
$\ln(DD_t)$	-2.777 (0)	-5.913** (1)	$I(1)$
$\ln(DS_t)$	-2.604 (1)	-7.455* (0)	$I(1)$
$\ln(OT_t)$	-2.666 (1)	-4.603** (0)	$I(1)$

[a] TV_t, BR_t EX_t, DD_t, DS_t, and OT_t represent the total volume of coal, barge rates, quantity of coal exports, quantity of domestic demand of coal, quantity of domestic supply of coal and rail rates, respectively. * and ** denote the rejection of the null hypothesis of non-stationarity at the 10% and 5% significance levels, respectively. The 10% and 5% critical values for the DF-GLS, including a constant and a trend, are -2.890 and -3.190, respectively. Parentheses are lag lengths, which are chosen by the Schwarz criterion (SC).

With evidence that each of the data series is a non-stationary $I(1)$ process, the FM-OLS is applied to estimate the long-run relationship in Equation (2). First of all, the result of the DF-GLS test performed on the residual from the estimated Equation (2) shows that the null hypothesis can be rejected at the 5% significance level (Table 2), suggesting the existence of long-run relationships between TV_t and the set of explanatory variables (BR_t, EX_t, DD_t, DS_t, and OT_t) in Equation (2). In other words, even though individual series may have trends or cyclical or seasonal variations, the movements in one variable are matched (at least approximately) by movements in other variables (Perman 1991).

Additionally, the results shows that the barge rate is not statistically significant even at the 10% level, indicating that in the long run a change in barge rates has little effect on the quantity of coal shipped by barge (Table 2). One plausible explanation for the finding is that, since barge rates are substantially lower than the rates of alternative transportation modes (i.e., rail rates), barge is the only economically viable transportation option for coal movements in the current system of the U.S. inland waterways, regardless of barge rate fluctuations.[10] Similarly, the rail rate is found to be statistically insignificant at the 10% level, suggesting that rail rates play little role in influencing the quantity of coal shipped by barge transportation in the long run. One explanation for this finding is that, while water transportation generally has a service disadvantage (i.e., slow transit time), its better accessibility from coal mines to coal-fueled power plants tends to reduce the substitution effect to rail service.[11] This may allow the demand for coal barge transportation to be highly insensitive to a change in rail rates. On the other hand, the quantity of coal exports is found to have a significantly positive long-run relationship with the volume of coal barge movements; for example, a 1% increase in exports causes barge shipments of coal to increase by approximately 0.38%. The quantity of domestic demand for coal is also found to have a significantly positive long-run relationship with the quantity of coal barge service; for example, coal barge shipments increase by approximately 2.14%, given a 1% increase in the quantity of domestic demand of coal. However, the quantity of domestic supply of coal has little effect on the demand for coal barge service. Hence, the findings show that the demand for coal barge transportation is mostly determined by demand for coal at domestic and international destinations, rather than the supply of coal or barge and rail rates.

Table 2: Result of the Fully-Modified OLS (FM-OLS) Estimation[a]

Variable	**ln (TV_t)**	
	Coefficient	**-statistic**
ln (BR_t)	0.084	0.536
ln (EX_t)	0.381	2.137**
ln (DD_t)	2.137	2.175**
ln (DS_t)	-0.037	-0.045
ln (OT_t)	0.001	0.003
Constant	-12.573	-2.796**
DF-GLS statistic	-4.699 [0]**	

[a] TV_t, BR_t EX_t, DD_t, DS_t, and OT_t represent the total volume of coal, barge rates, quantity of coal exports, quantity of domestic demand of coal, quantity of domestic supply of coal and rail rates, respectively. * and ** denote significance at the 10% and 5% levels, respectively. A bracket in the DF-GLS statistic is lag length. The 10% and 5% critical values for the DF-GLS, including a constant and a trend, are -2.890 and -3.190, respectively.

For completeness, the error-correction model (ECM) is also estimated using the residual obtained from Equation (2) in order to examine the short-run adjustment to the long-run steady state, as well as to confirm the existence of the cointegration relationship (Table 3). The results show that the coefficient of the error-correction term (ec_{t-1}) is negative and statistically significant at the 5% level. The negatively significant coefficient of ec_{t-1} implies that the equilibrium relationship will hold in the long run, even with shocks to the system. Additionally, the statistically significant ec_{t-1} further supports the validity of cointegrating relationship in Equation (2). The multivariate diagnostic tests on the estimated model as a system indicate no serious problems with serial correlation, heteroskedasticity, and normality; hence, the model is well defined. Notice that the domestic supply of coal is only found to have a significantly positive effect on the demand, indicating that the supply of coal is a crucial determinant of the demand for coal barge transportation in the short run.

Table 3: Result of Error-Correction Model (ECM)[a]

Variable	**$\Delta\ln(TV_t)$**	
	Coefficient	**-statistic**
$\Delta\ln(BR_t)$	0.312	1.46
$\Delta\ln(EX_t)$	-0.071	-0.29
$\Delta\ln(DD_t)$	-1.286	-0.78
$\Delta\ln(DS_t)$	1.831	2.31**
$\Delta\ln(OT_t)$	0.861	1.13
Constant	0.033	0.586
ec_{t-1}	-0.989	-3.31**
Serial correlation	0.444 [0.652]	
Heteroskedasticity	0.003 [0.954]	
Normality	0.741 [0.954]	
RESET	0.894 [0.362]	

[a] TV_t, BR_t EX_t, DD_t, DS_t, and OT_t represent the total volume of coal, barge rates, quantity of coal exports, quantity of domestic demand of coal, quantity of domestic supply of coal and rail rates, respectively. * and ** denote significance at the 10% and 5% levels, respectively. A bracket in the DF-GLS statistic is lag length. The 10% and 5% critical values for the DF-GLS, including a constant and a trend, are -2.890 and -3.190, respectively. Serial correlation of the residuals of a whole system is examined using the F -form of the Lagrange-Multiplier (LM) test. Heteroskedasticity is tested using the F -form of the LM test. Normality of the residuals is tested with the Doornik-Hansen test (Doornik and Hendry 1994). Statistics in brackets are p -values.

CONCLUDING REMARKS

This paper explores the demand for coal barge transportation on the U.S. inland waterway system in a cointegration framework. Previous studies have mostly examined the demand for grain barge transportation and barge rates, but little attention has been given to factors determining coal barge shipments and the substitution effect between water and rail services for coal shipments. Using a FM-OLS approach, this paper examines the dynamic interrelationships between the demand for coal barge transportation and barge rates, rail rates, domestic coal consumption, domestic coal production, and coal exports. The results of the FM-OLS suggest that there is one stable long-run equilibrium relationship between the demand for coal barge transportation and the selected variables. The negatively significant coefficient of the error-correction term in the vector error-correction model further validates the existence of an equilibrium relationship among the variables. The results also show that, in the long run, the demand for coal barge transportation is mostly responsive to the domestic coal exports and domestic coal consumption, rather than barge and rail rates. In the short run, on the other hand, domestic coal production is the only significant determinant of the demand for coal barge transportation.

Currently, the U.S. Army Corps of Engineers (USACE) builds, maintains, and plans all infrastructure needs for the inland waterway system, yet insufficient information hinders its ability to develop the comprehensive regional investment plans to support freight movements and energize the economy. The information derived from this paper may help policymakers develop better infrastructure strategies and improve investment decisions for the inland waterway system. The U.S. inland waterway system has 230 lock sites, which include 275 lock chambers that support coal shipments. The crucial factors identified in this paper can be used to help predict coal traffic at lock sites in the short and long run and assess the lock investment projects. For barge carriers, on the other hand, the information obtained from this paper will be valuable in implementing their labor and capital investment plans.

Finally, it should be pointed out that, although this study conjectures that more disaggregated demand structures (data) is both desirable and necessary to provide more useful information about investment decisions for the inland waterway system, limited data availability does not allow making future analysis to examine the validity of this conjecture. In addition, this paper does not consider major policy and market shocks in the model that may result in a significant change in the demand for coal barge transportation. For example, does the partial deregulation (or mergers) of railroad companies in the United States affect demand for barge transportation? How does the Clean Air Act Amendment of 1990 influence shipments of coal volumes transported via the inland waterway system? All these issues should be addressed in future research.

Endnotes

1. Water carriers are known to compete with rail carriers for the shipments of bulk commodities for long hauls. While water and rail transportation modes are empirically found to be partial substitutes for grain movements (e.g., Miljkovic et al. 2000), the substitution effects between these two modes have not been investigated for coal barge shipments.

2. Some of the previous literature has indeed investigated the presence of a unit root in their time-series variables using the augmented Dickey-Fuller (ADF) test (Thoma and Wilson 2004a, Yu et al. 2007). However, when dealing with finite samples, the power of the standard ADF test is known to be notoriously low (Maddala and Kim 1998, Harris and Sollis 2003). In other words, the ADF test has high probability of accepting the null hypothesis of non-stationarity when the true data-generating process is, in fact, stationary. Therefore, to overcome the shortcoming of the ADF, this paper adopts a more powerful test known as the Dickey-Fuller generalized least squares (DF-GLS) detrended test.

3. In this paper, truck transportation is not considered as a substitute of barge service for coal shipments, because truck transportation is not an economical transportation option for bulk commodities and raw materials for long hauls.

4. It is worth mentioning that the FM-OLS uses a cointegration framework to take into account the non-stationarity in the series as well as potential endogeneity of the explanatory variables and serial correlation of the error term. More specifically, in general, TV_t and BR_t are endogenously determined in equation (2); by definition, BR_t in this case is likely to be correlated with the error term ε_t, which causes the OLS estimators to be biased. Additionally, when using the traditional OLS, the Durbin-Watson (D-W) test shows that equation (2) is suffering from AR(1) serial correlation at the 5% level. To solve these problems, this paper uses the FM-OLS to estimate equation (2). Hargreaves (1994) demonstrates that, particularly in small samples, the FM-OLS has been proven to be a fully efficient method of estimating the long-run equilibrium (cointegration) relationship.

5. A stationary series, or integrated of order zero (*I(0)*) is defined as a series that tends to return to its mean value and fluctuate around it within a more or less constant range. A non-stationary series (unit roots), on the other hand, is defined as a series that has a different mean at different points in time and its variance increases with the sample size (Harris and Sollis 2003). Since OLS regression with non-stationary series no longer provides the valid interpretations of the standard statistics (i.e., t - and F -statistics), non-stationary variables should be differentiated to make them stationary. Integrated of order one, *I(1)*, is a time-series process that needs to be first-differenced to produce a stationary series, or *I(0)*, which is often said to be a (first) difference-stationary process (Wooldridge 2006). The first difference of a time series means the series of changes from one period to the next. However, Engle and Granger (1987) show that,

even in the case that all the variables in a model are non-stationary (i.e., *I(1)*), it is possible for a linear combination of integrated variables to be stationary (i.e., *I(0)*); in this case, the variables are said to be cointegrated.

6. A drift parameter is usually said to be a random walk with drift. A random walk means a time series process where next period's value is obtained as current period's value, plus an independent error term. A random walk with drift means a random walk that has a constant (or trend) added in each period (Wooldridge 2006).

7. The explanatory (independent) variables and error terms are correlated in the same time period (Woodridge 2006). An explanatory variable is a variable that is used to explain variation in the dependent variable. An error term means a variable that contains unobserved factors that affect the dependent variable.

8. EIA collected coal transportation rates primarily from coal burning utilities and they are not necessarily available to industrial customers that tend to purchase coal under smaller supply contracts. According to EIA (2004), the weighted average rates are actual averages as individual rates and mine price outliers are not included. The rates represent coal delivered under contract and excludes coal deliveries scheduled for 12 or fewer months, commonly referred to as spot coal purchases.

9. River Transport News (1993-current) could be used as an alternative rate data source but it is difficult to estimate the annual average rates from the insufficient number of the samples.

10. In 2000, for example, the average domestic barge rates for coal and rail per ton are $2.26 and $10.30, respectively (U.S. Energy Information Administration 2004).

11. U.S. Army Corps of Engineers (2005) reports that in the case of lock closure at McAlpine on the Ohio River in Louisville, Kentucky, the most frequent response from survey respondents is to wait until lock operation resumes and do not switch to rail service. High rail rates and inaccessibility to loading/unloading rail facilities restrain the shippers' ability to switch their transportation modes.

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