Rejuvenating Mississippi River's Post-Harvest Shipping

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The Mississippi River inland waterway system plays an integral part in both domestic and international North America trade. It plays a vital role in the global competitiveness of U.S. agricultural commodities, aids in the sustainability of alternative energy production, and provides competition to both rail and truck transportation. Currently, over 60% of U.S. agricultural exports traverse sections of the over 2000 miles of barge navigable waterways (Edke, 2011). With increased international competition from developing agricultural exporters including Brazil and Argentina as well as the Panama Canal expansion, maintaining an efficient Mississippi River transportation system is vital to our economy as a whole. If this transportation system cannot grow and adapt, the United States export industry may not maintain its comparative advantages.

A key to the river's effectiveness is its efficiency in carrying bulk loads on barges. Efficiency is defined as lower average costs of transportation associated with market induced lower barge rates. This efficiency is a direct function of barge transit speed and load size. Literature related to Mississippi barge transportation efficiency has generally focused on quantifying how infrastructure improvements to the lock and dam system can decrease the travel time of a barge across river segments. In light of an aging river infrastructure system, research has examined the extent current lock delays and closures reduce barge transportation efficiency and divert agricultural commodity transportation from barges to substitute means of transportation (Corps of Engineers, 2010; Fuller and Grant, 1993; Gervais et al., 2001; Yu et al., 2006). Results reveal a relatively weak relation between current lock delays and barge rates. However, limited or no research has investigated how barge-load size affects efficiency and it is hypothesized that the correlation may be stronger than that of lock delays. An analysis of barge load size on efficiency can lead to improved policies in regulating this crucial transportation system.

Barge draft depth is a measurement of the submerged portion a barge and is directly related to its load size. Once inch of draft depth in a standard barge is equal to 17 tons of cargo, which is roughly the weight of a semi-truck. However, a barge's load size and resulting draft depth are often constrained by the current physical characteristics of the river. Thus, the aim is to investigate on how loaded barge-draft depth affects barge rates. The testable hypothesis is: draft depth influences barge rates; yielding improved understanding of barge-rate dynamics. Specifically, economic theory indicates a negative relation between draft depth and barge rates. The question is whether the empirical results support the theory and if so what are the relative magnitudes of the relationship.

For empirical testing of the hypothesis, a vector autoregressive model on barge rates and draft depths is developed. Results support the initial hypothesis. The magnitude of the responsiveness of barge rates to draft depth is relatively strong. This indicates barge-rate volatility may be greatly reduced through Army Corps of Engineers developing policies regulating draft depth. In contrast to studies on lock delays, river depth does significantly mitigate barge-rate volatility. Based on the empirical results, an elementary benefit-cost analysis is employed to determine the economic and environmental feasibility of deepening the river channel by an additional one foot. Results indicate the Army Corps may want to consider a thorough analysis of channel deepening.

Literature

Previous literature surrounding inland waterway barge freight rates has focused on its effects on ocean freight-price and grain market volatility. Haigh and Bryant (2008) employ a generalized autoregressive conditional heteroscedasticity model and conclude barge rate volatility has a larger impact on grain prices than do ocean freight rates. Similarly, Harnish and Dunn (1998) determine that barge and ocean freight price risk have significant impacts on the price risk of domestic grain markets. Chi and Jungho (2015) employ a vector error correction model for investigating the long- and short-run dynamics of barge rates and corn production. They determine, in the long run, barge rates and corn production are weakly exogenous and have significant effects on the demand for corn barge transportation. In the short run, rail rates and corn consumption significantly impact changes in demand for corn barge transportation.

Previous literature concerning the efficiency of Mississippi River barge transportation generally focuses on infrastructure improvements to the lock and dam system. As a result of high investment costs, as well as increased delays during an extended construction time for renovating a lock, much of the related research concerning transportation efficiency focuses on cost-benefit analysis. Current estimates from the Corps of Engineers (2010) indicate it would cost approximately $3 billion dollars to renovate the aging lock system to full working order, let alone adding new locks or expanding the existing locks to accommodate increased river traffic and tow size. Fuller and Grant (1993) examine the extent current lock delays divert agricultural commodity transportation from barges to other means of transportation. Their findings indicate increased lock delays did divert some agricultural commodities to alternative forms of transportation. However, a weak relation was revealed between the quantity of displaced commodity movement and barge rates. Gervais et al. (2001) conducted a study that identified critical locks, which may induce bottlenecks that increase transit time. They determine improving a few selected locks would provide only minimal efficiency gains and would not significantly improve the competitiveness of U.S. farmers in world markets. However, the magnitudes of the estimated coefficients did suggest continued deterioration of the locking system could increase barge rate volatility and reduce efficiency. Yu et al. (2006) link lock delays to barge transportation efficiency by employing a vector autoregressive model. Results suggest the strongest relation affecting barge rates in different segments, apart from own lagged values, are the lagged values of barge rates in neighboring segments. If barge rates in a particular segment can be reduced by increasing barge supply, barge rates in neighboring segments will also decline. Thus, if a river segment can increase the overall speed with which it can process barges, barge rates for the entire river system may decrease. Upon examining traffic spikes however, there was either no or a very weak relation concerning travel speed and barge rates. This indicates while the average speed of barge transportation through its entire course has a significant impact on barge rates, individual locks with relatively high delays were largely insignificant when taking into account the entirety of a barge’s trp. Even in the case where overall total travel and delay time is significant, estimated rate equations indicate an inelastic value of 0.045. A 1% decrease in delay time will decrease barge rates to lower Mississippi ports by only 0.045%. Thus, the results indicate a relatively weak relation between individual lock delays and barge rates without renovating the entire waterway infrastructure system

The literature indicates little or no relationship between reducing specific lock delay bottlenecks and increasing overall barge transportation efficiency. Based on this research, the Army Corps of Engineers has adopted lock infrastructure policies designed to maintain the current level of lock transportation efficiency rather than invest in large-scale multi lock improvements to increase barge transit speed (Corps of Engineers, 2010). Given the huge financial and time cost of upgrading the entire locking systems, the benefits of reduced congestion resulting from upgrades would have to be significantly larger. As an alternative method for improving the lock system, the National Academy of Sciences (2001) recommends nonstructural improvements including better-trained deckhands and lock operators and more efficient barge scheduling.

The literature review indicates research directed toward cost-benefit analysis of lock infrastructure improvements with a lack of research focusing on the relation of segment barge rates to draft depth. The objective is to fill this literature gap, which will lay the foundation for future in depth cost-benefit analyses and potential policies regarding draft depth in a similar manner to lock improvements.

Mississippi Barge Market

Barge rates and draft depths refer to bulk commodity barges (nine-foot covered hopper barges), which accommodate over half of commodity transportation traffic on the Mississippi River. The term nine-foot defines bulk commodity barges, which maximize the use of the nine-foot depth channel maintained by the Army Corps of Engineers. With the Army Corps objective to maintain the central Mississippi channel to a minimum depth of nine feet, the majority of commercial commodity transportation employs barges that operate at this level. The draft of a barge is a vertical measure of the submerged portion. The barge is covered by removable sections, which protect the cargo during transit and are removed when loading or unloading. Each barge can carry 1500 tons of cargo, which are 15 and 60 times the capacity of a rail car and semi-trailer truck, respectively (Sparger and Marathon, 2015). These barges are not self-propelled and are linked together to form a tow. An average river tow on the Upper Mississippi River consists of 15 barges, typically attached in a rectangle formation with five barges long and three abreast. The equivalent load to a 15 tow barge is a train three miles long or a line of trucks stretching more than 35 miles. Figure 1 illustrates the composition of the Mississippi barge fleet in 2002. Out of these barge types, covered dry cargo barges constitute approximately half of the barge fleet. Nine-foot covered dry cargo barges are thus the focus as they represent the most common barge type on the Mississippi River. Agricultural commodities such as grain and oilseeds must be protected from the weather, and thus these covered dry cargo barges transport the vast majority of agricultural commodities on the Mississippi River.

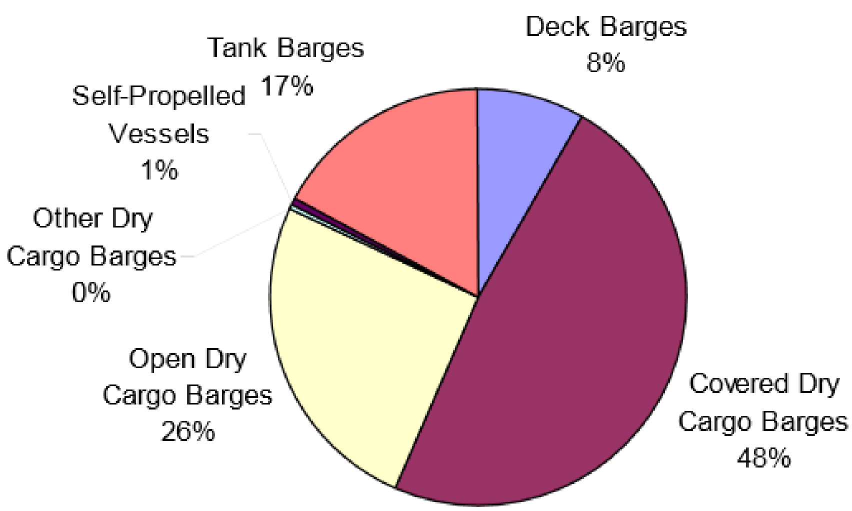


Figure 1. Mississippi River Barge Type by Percentage, 2002 (Corps of Engineers, 2004)

A chief aspect of the efficiency of barge transportation is the effectiveness with which the river can carry bulk loads. The exceptionally low dollar per-ton cost to transport commodities on a barge from a point on the river to an export destination on the gulf compared to other means of transportation is a major contributor to the comparative advantage the United States enjoys in international trade. This efficiency is directly affected by barge speed and load size. If large loads are able to be transported quickly down river, then barge rates will decline. Barge transportation benefits from economies of scale, and theory states the per-ton cost to ship commodities by barge should decrease the larger the load a barge is able to carry. Thus, policy decisions concerning Mississippi barge transportation should be concerned with ensuring cheap and efficient barge transportation. This can be done in a cost effective manner by maximizing the draft depth of a barge.

Barge Rates and Draft Depth

For analysis, the river is dissected into five distinct segments consisting of the Illinois, Upper Ohio, Lower Ohio, Lower Mississippi (MTCT), and St. Louis rivers (Figure 2). This collection of river segments comprises over 2000 miles of barge navigable waterways whose locks, dams, and channels are maintained by the Army Corps of Engineers. The cost to ship commodities between a specified river segment and an export demand node in the River Gulf export region is given by the cost to traverse the locks. The Bulk Grain and Grain Products Freight Tariff Number 7, instituted by the Waterways Freight Bureau (WFB) was originally set up to regulate barge pricing. Under this system, each lock had its own unique tariff rate measured as a dollar per ton cost to ship commodities between that lock and a destination port in Louisiana. These tariff rates were dictated by the Interstate Commerce Commission, which had control over setting barge transportation rates (National Academy of Sciences, 2001). Since 1976, WFB no longer exists and market forces are allowed to determine barge rates with 1976 tariffs as benchmarks.

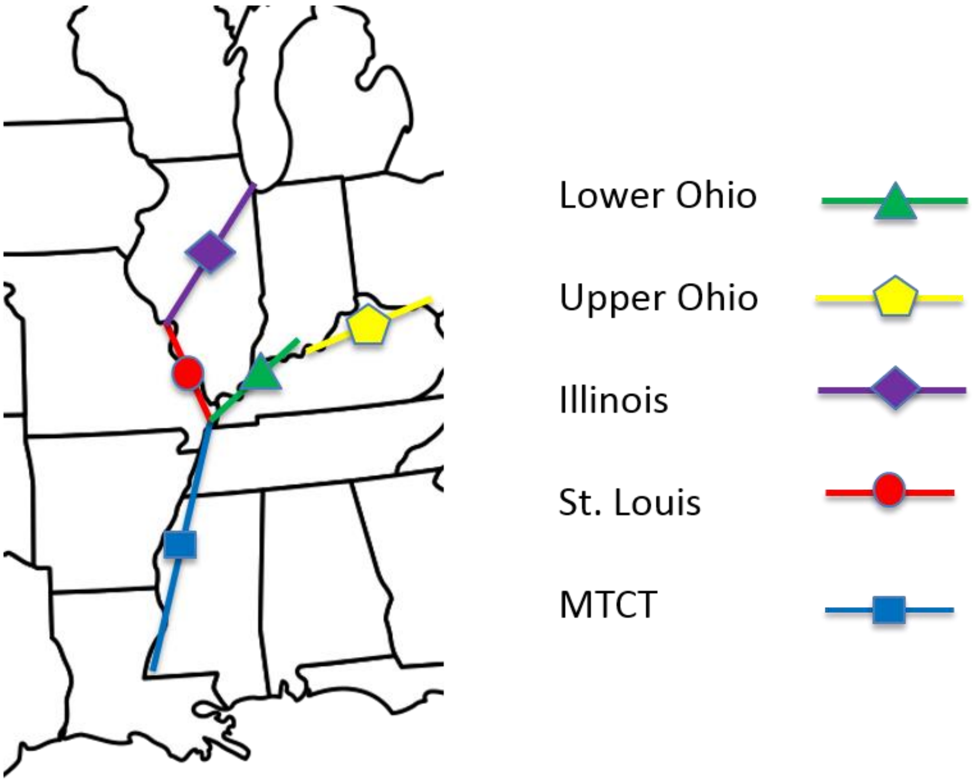


Figure 2 Mississippi River Segments under Study

Barge operators on the Mississippi River employ a barge percent-of-tariff (BPOT) as the price of commodity transportation on the river. Market forces then result in stochastic barge rates over time. Multiplying the stochastic BPOT rate at a given time by the fixed historic tariff rate for a specific lock within a given segment provides a dollar/ton price for shipping commodities at a specific time. This price is the cost per ton to ship a commodity from its starting location to a demand export location in the Gulf. Overall, benchmark tariff rates vary from approximately $2.00 to $7.00 per ton and are higher the farther north the lock location. Figure 3 displays the barge rate in a real dollar per ton value after the benchmark rates are multiplied by the BPOT system for the five river segments over a ten year interval, using 2010 as a base year.

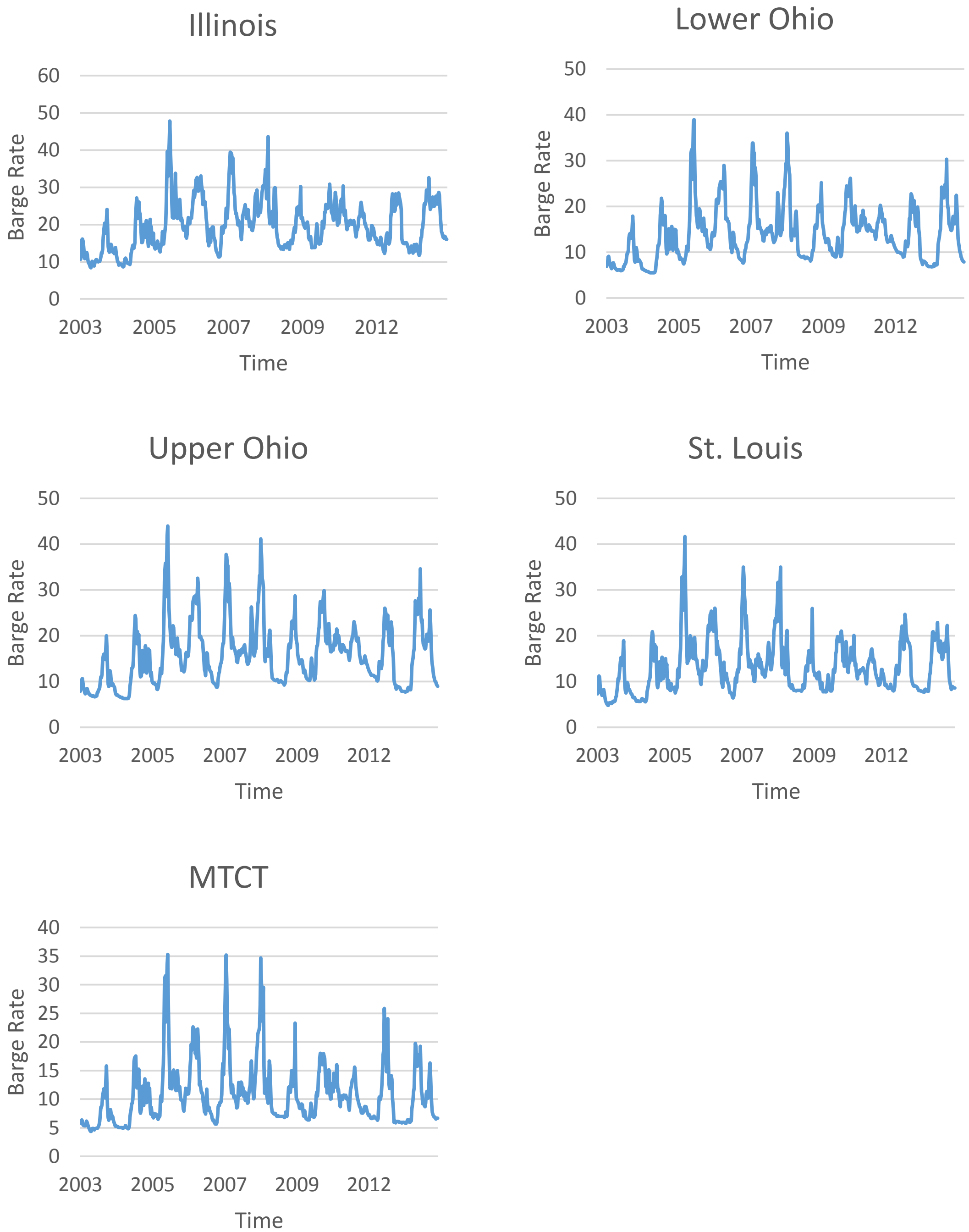


Figure 3 Real $/Ton Barge Rates by Segment

The Army Corps of Engineers attempts to maintain a minimum dredging depth of nine feet, but during periods of drought and sediment shifting the depths are sometimes lower. However, most of the volatility in draft depths arises when natural river conditions permit barges to be loaded deeper than nine feet. When river conditions are calm and sufficiently deep, barges can be loaded to a maximum draft of around 12½' to 13'. In these cases, theory would predict potential lower barge rates as each barge can accommodate a larger load requiring fewer barges to be contracted, and in essence increasing total barge transportation supply. Thus, the signs and magnitudes of the effect of draft depths on barge rates in different river segments can have important policy implications. For example, they can help dictate which segments have priority for the Army Corps to dredge in order to maintain barge draft depth. Further, cost-benefit analysis could investigate the viability of increasing barge transportation efficiency by increasing draft depths in specific segments.

Market Structure

Miljkovic et al. (1999) concluded the amount of barge usage is determined by market forces through the actions of buyers and sellers. No information asymmetries exist as both parties employ readily available information to establish an equilibrium rate. Thus, in addition to draft depth, the main variables considered are those that influence barge supply and demand. In this analysis, variables of barge supply and demand are identified and incorporated. Conclusions regarding barge rates, including the effect of draft depth, are then quantified and examined.

Considering supply, the size of the available barge fleet should directly influence barge supply. Baumel (2008) indicates a large percentage of the estimated 20,000 barge fleet was purchased in the 1990s when many barge operators renovated their fleet. With a typical working barge life expectancy of approximately 30 years, the size of the barge fleet has remained relatively constant (Baumel, 2008). Few barges were retired or replaced during the analysis timeframe. As a result, the aspect of barge supply captured is the availability of barges in a specific river segment rather than total number of barges on the river. Grain movements can serve as a proxy for barge supply availability within a segment. The U.S. Agricultural Marketing Service tracks grain barge movements, defined as weekly totals of grain movements on barges through locks. This variable is similar to the barge count variable employed by Yu et al. (2006), who examined barge transit speed and included in the model for barge freight. Diesel price is another variable affecting barge rates as it is a main input price to barge transportation. An increase in fuel prices can negatively affect the availability of barges. Wholesale diesel prices are available from the U.S. Department of Energy. The nominal diesel price along with barge rates were deflated by the Producer Price Index (PPI) for All Commodities (series WPU00000000), available from the Bureau of Labor Statistics (BLS) with the base year of 2010. Real prices for barge rates are used to capture the effects of supply and demand when modeling.

In conjunction with previous literature, agricultural commodity movements can act as a proxy variable for barge demand and are included in this analysis. Covered dry cargo barge demand is primarily driven by the transportation of agricultural commodities (Miljkovic et al., 1999). More than 90% of corn and soybean exports from the Gulf of Mexico are transported to their export destination by barges on the Mississippi (Miljkovic et al., 1999). The majority of this grain is destined for international markets such as China and Japan and is transported by large oceangoing vessels. The number of oceangoing grain vessels loading in the Gulf region can capture the magnitude of covered cargo barge transportation demand. Measured by the USDA

Grain Inspection, Packers, and Stockyards Administration, this variable is a weekly count of the number of oceangoing grain vessels scheduled for filling at the Gulf Coast ports.

Another variable affecting barge demand is the level of U.S. corn stocks; available from the National Agricultural Statistics Service. Corn is the largest agricultural commodity produced in the United States by both weight and volume and as a result is the main commodity transported by these barges. Corn storage and harvest timing accounts for the seasonality inherit in barge rates. When corn stocks are trending down (up) this would suggest an increase (decrease) in barge demand resulting in higher (lower) barge rates as elevators are no longer (continuing) storing grain corresponding to a strong (weak) demand for export destinations.

Although covered barges represent only half of the total barge fleet, they comprise an estimated 87% of total down bound commodity traffic with the vast majority transporting agricultural commodities. Thus, the grain movement, national stock, and export variables are accurately focused on the downstream movement of agricultural commodities as a proxy for covered hopper barge supply and demand. Variables specifically relating to the upstream transportation of covered hopper barges are not included. Previous work concerning barge freight rates have also focused on the transport of agricultural commodities and do not include specific variables to account for upstream transportation (Haigh and Bryant, 2001; Fuller and Grant, 1993; Miljkovic et al., 1999).

In discussing how prices in neighboring river segments affect each other, it should be noted that once a barge is loaded in a given segment, its cargo is typically transported all the way down to export destinations on the Gulf Coast. This interaction is inherently underlined by the manner in which barge rates are quoted. The barge percent of tariff of a lock is the cost of transportation between that specific lock location and the Gulf coast. These downstream interactions result in a one directional relation where upper segments are affected by lower segments. Thus, barge rates in a given segment are a function of their own lagged price and the lagged price of segments below it. If the barge rate in a lower segment were to increase, barges traveling upriver may stop at this segment, which would reduce the barge supply of segments farther up the river. If the barge rate were to increase in a higher segment however, the supply of unbound empty barges must still pass by the lower segments and will not impact their barge supply.[1]

The interactions among segment draft depths are also constrained in the same manner as the price interactions among segments. The effects of a segment's draft depth upstream from a given segment are constrained to be zero. With the majority of loaded grain barges traveling downstream, barge operators are only concerned with river levels downstream of their loading site. By including draft depths of lower segments, it is possible to consider dredging policy impacts on barge rates in different segments simultaneously. For improved river efficiency, the Army Corps could potentially prioritize dredging in specific segments or increase the depth to which they dredge, which may affect not just that segment but segments above it as well. Table 1 lists the five river segments and which price and draft variables are included in their respective functions. The expected signs of all the included variables are listed in Table 2.

Table 1. Directionally Constrained Segment Interaction

Illinois	St. Louis	Upper Ohio	Lower Ohio	MTCT
Illinois	St. Louis	Upper Ohio	Lower Ohio	MTCT
St. Louis	MTCT	Lower Ohio	MTCT	
MTCT		MTCT		

Table 2. Expected Signs

Variable	Expected Sign
Lagged Price in Other Segments	+
Own Draft Depth	–
Draft Depth In Other Segments	–
Diesel Price	+
Ocean Vessel Count	+
Grain Movements	–
National Corn Stock	–

Data

For all the variables (barge rates, draft depths, diesel prices, corn storage, grain movements, and ocean vessels) weekly data is collected from January 2003 to June 2014, yielding 594 observations. The units of measurement and definitions are listed in Table 3 with summary statistics provided in Table 4.

Table 3. Definition of Variables

Segment Specific Variables	
Barge Rate ($/ton)	
Draft Depth (feet)	
Conditioning Variables (Non Segment Specific)	
Diesel Price ($)	National Diesel Price
National Corn Stock (bill bu)	Total U.S. National Corn Storage Volume
Grain Movement (mill tons)	Number of Tons of Grain that Traversed Key Locks
Ten Day Ocean Vessel Count	Grain Ocean Vessels to be Loaded in Next Ten Days

Table 4. Summary Statistics

	Mean	Minimum	Maximum	Standard Deviation	Skewness	Kurtosis
Barge Rates ($/ton)						
Illinois	19.70	8.38	47.81	6.58	0.72	0.65
Upper Ohio	15.86	6.29	43.95	6.77	1.00	1.13
Lower Ohio	13.99	5.51	39.00	6.02	1.06	1.37
St. Louis	13.13	4.80	41.67	5.70	1.28	2.32
MTCT	10.88	4.37	35.27	5.29	1.70	3.86
Draft Depth (feet)						
Illinois	9.47	8.00	10.36	0.29	−0.19	1.43
Upper Ohio	10.43	9.00	11.65	0.66	−0.36	−0.73
Lower Ohio	11.33	9.00	12.60	0.80	−0.94	0.53
St. Louis	10.90	8.60	12.60	1.11	−0.14	−1.23
MTCT	10.39	9.00	11.60	0.61	−0.42	−0.66
Conditioning Variables						
Diesel Price ($)	2.99	1.73	4.10	0.344	0.39	1.20
National. Corn Stock (bill bu)	5.08	0.80	10.90	2.51	0.17	−0.87
Grain Movement (mill tons)	6.39	1.18	13.33	1.96	0.13	0.23
Ten Day Ocean Vessel Count	56.83	18	97	13.32	0.37	−0.24

Barge rates have a relatively high variance with both a positive skewness and kurtosis. This indicates distributions with right tails and more peaks. In contrast, draft depths have left tail distributions with no consistency in the peaks. The standard deviations of draft depths are relatively small, which indicates the Army Corps of Engineers efforts to continually dredge to maintain a nine-foot draft depth. In terms of the conditioning variables, ocean vessels have a relatively large standard deviation with close to a normal distribution. This is in contrast to diesel prices with relatively small standard deviations, but high kurtosis.

The Augmented Dickey-Fuller test rejected a unit root for barge rates and draft depths in each segment along with the other explanatory conditioning variables at the 1% significance level. Similar tests for unit roots including the Phillips-Perron test yield the same results.

Model

For empirically testing the hypothesis of a negative relation between barge rates and draft depths and to gain increased understanding of barge rate dynamics from the conditioning variables, a time series vector autoregressive with exogenous variables (VARX) model on barge rates is developed. The representation of a downstream directional p lag order VARX model, VARX(p) with N river segments and T weeks can be modeled as:

$$Y_{n,t} = c_n + \sum_{n=r_n}^{N} \sum_{p=1}^{P} \alpha_{n,p} Y_{n,t-p} + \sum_{n=r_n}^{N} \gamma_n Z_{n,t-p} + \beta X_{n,t-1} + \varepsilon_{n,t},$$

where $Y_{n,t}$ is a NT×1 vector of segment barge rates per weeks, $N-r_n$ is the number of downstream segments from segment n, $Z_{n,t-p}$ is a vector of draft depths, $X_{n,t-1}$ is a k ×1 vector of lagged exogenous variables, c_n is a constant term, α, γ, and β are parameters to be estimated, and $\varepsilon_{n,t}$ is a white noise error term.

Each of the exogenous conditioning variables including draft depth is lagged once. It is hypothesized that the current draft depth and grain movement variables affect barge prices in the next week. Furthermore, the travel time for a barge from its loading point to the Gulf Coast necessitates lags in the exogenous variables. A change in an exogenous variable in a current week affects the supply and demand of barges, but this impact will only be fully realized in the market a week later once the barge has completed its trip.

The lag length for estimating the VARX model is determined by the Akaike information criterion (AIC), Bayesian information criterion (BIC), and the Hannan and Quinn information criterion (HQIC). Based on these criterion, a lag length of three was selected for a VARX(3) model.

In this directionally constrained model, the price in each segment is taken as a function of its own lagged price, the lagged prices of segments down river, its own draft depth, the lagged draft depth of segments down river, and a set of exogenous conditioning variables. Table 5 lists the results of this directionally restricted VARX model.

Results

As indicated in Table 5, each of the exogenous conditioning variables (Diesel Price, National Corn Stock, 10 Day Ocean Vessels, and Grain Movements) have the expected signs. Grain Movements at a 10% significance level negatively impacted barge rates on the Upper and Lower Ohio segments. The National Corn Stock negatively impacts barge rates at the 1% significance level across all five segments. Note there is no statistical difference among the national corn stock variables so they are restricted to be the same across the five segments.

In terms of draft depths, a segment's own draft depth coefficient is negative and significant at the 5% level. Only the Upper Ohio Draft was not significant at the 10% level. However, the Illinois Draft coefficient was significant at the 1% level with the wrong hypothesized sign. As listed in Table 4, the Illinois draft depth has the lowest mean, minimum, and maximum values along with the lowest standard deviation. As a possible explanation for the sign of the interaction, this indicates although the relative low Illinois draft depth may universally result in higher barge prices, the resulting estimated coefficient is less reliable for large changes in the draft depth. In terms of the draft depth relationships across segments, the draft depth of the MTCT and Lower Ohio segments are significant at the 5% level for St Louis and Upper Ohio equations, respectively.

Table 5 Directionally Constrained Vector Auto Regressive Results

	Illinois	St. Louis	Upper Ohio	Lower Ohio	MTCT
Illinois					
Barge Rate$_{t-1}$	0.843***				
	(0.040)				
Barge Rate$_{t-2}$	−0.215***				
	(0.052)				
Barge Rate$_{t-3}$	0.100***				
	(0.038)				
St. Louis					
Barge Rate$_{t-1}$	0.270***	0.834***			
	(0.080)	(0.040)			
Barge Rate$_{t-2}$	−0.157	−0.197***			
	(0.098)	(0.051)			
Barge Rate$_{t-3}$	0.062	0.098***			
	(0.079)	(0.038)			
Upper Ohio					
Barge Rate$_{t-1}$			0.517***		
			(0.041)		
Barge Rate$_{t-2}$			−0.057		
			(0.046)		
Barge Rate$_{t-3}$			0.092**		
			(0.040)		
Lower Ohio					
Barge Rate$_{t-1}$			0.503***	0.924***	
			(0.062)	(0.039)	
Barge Rate$_{t-2}$			−0.239***	−0.229***	
			(0.077)	(0.053)	
Barge Rate$_{t-3}$			0.045	0.108***	
			(0.061)	(0.036)	
MTCT					
Barge Rate$_{t-1}$	0.031	0.322***	0.311***	0.324***	1.170
	(0.080)	(0.058)	(0.052)	(0.047)	(0.040)
Barge Rate$_{t-2}$	0.061	−0.198**	−0.185***	−0.205***	−0.452
	(0.106)	(0.080)	(0.072)	(0.064)	(0.060)
Barge Rate$_{t-3}$	−0.011	0.061	0.007	0.027	0.173
	(0.078)	(0.057)	(0.052)	(0.046)	(0.040)

Table 5 continued

	Illinois	St. Louis	Upper Ohio	Lower Ohio	MTCT
Draft Depth					
Illinois	0.381***				
	(0.155)				
Lower Ohio			−0.170**	−0.147**	
			(0.083)	(0.072)	
MTCT	−0.077	−0.196**	−0.082	−0.094	−0.348***
	(0.138)	(0.118)	(0.110)	(0.098)	(0.104)
St. Louis	−0.041	−0.162***			
	(0.075)	(0.044)			
Upper Ohio			−0.045		
			(0.113)		
Exogenous Variables					
National Corn Stock	−0.078***	−0.078***	−0.078***	−0.078***	−0.078***
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
10 Day Ocean Vessels	0.009	0.006	0.010	0.008	0.006
	(0.007)	(0.007)	(0.006)	(0.006)	(0.006)
Diesel Price	−0.370	−0.290	−0.115	−0.097	−0.130
	(0.271)	(0.249)	(0.234)	(0.211)	(0.234)
Grain Movements	−0.034	−0.032	−0.073*	−0.063*	−0.026
	(0.049)	(0.045)	(0.043)	(0.038)	(0.043)
Constant	1.110	6.597***	5.153***	4.402***	5.754***
	(2.142)	(1.543)	(1.550)	(1.391)	(1.447)

Standard errors are in parentheses with *, **, and *** denoting statistical significance at the 10%, 5% and 1% level, respectively.

In examining the results of the lagged prices and the interactions among them, at least the first lag of a segment's own price and the first lag of prices in segments downstream are significant at the 1% level with the exception of the interaction between the Illinois segment equation and the lagged value of the MTCT segment. Also, the MTCT equation indicates no significance at the 10% level for the lagged price coefficients. This phenomenon can be explained by the decline in the magnitude of the coefficients between segment barge rates as the distance between the segments increase. As the distance increases there is an expected decay in the importance of price interaction between segments. For each of the three lags of barge rates, the first lag is positive followed by a negative second lag and then followed by a positive third lag. In each lagged price however, the first lag contributes the majority of the significance to the respective segment equation. To indicate the magnitudes of segment interaction from the included variables, the elasticities are calculated for the significant variables (Table 6).

All the elasticity values are inelastic indicating barge rates are responsive but not overly responsive to draft depth. Additionally, barge rates in the St. Louis segment are significantly impacted by draft rates in the MTCT segment. Thus, results from this model suggest that maintaining the nine-foot channel in the MTCT segment is of potentially greater relative importance than up-stream segments.

For comparison of this impact, Yu et al. (2006) estimated an elasticity of 0.045 for barge rates response to lock delay times. In contrast, the associated draft-depth elasticities, displayed in Table 6, are generally over three times in magnitude. Not only is the responsiveness of barge rates markedly larger for draft depth than for river delays, the Army Corps spends a much larger percentage of its budget on lock improvements and maintenance versus river dredging and costs to maintain the river channel. These results suggest a renewed cost-benefit analysis of alternative programs designed to improve river efficiency may be warranted. If the costs to increase the draft depth in these segments is lower than the costs to reduce lock delays for a given improvement in river efficiency, then policies designed to improve barge transportation should potentially consider draft depth over lock improvements.

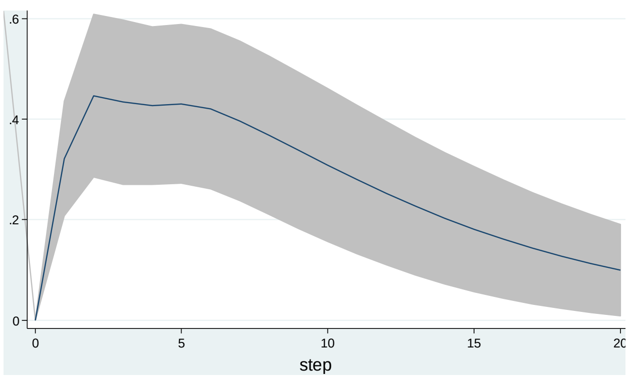
Table 6 Elasticities

	Illinois	St. Louis	Upper Ohio	Lower Ohio	MTCT
Draft Depth					
Illinois	0.183				
Lower Ohio			−0.112	−0.119	
MTCT		−0.155			−0.332
St. Louis		−0.134			
Upper Ohio					
Exogenous Variables					
Diesel Price					
National Corn Stock	−0.020	−0.030	−0.025	−0.028	−0.036
10 Day Ocean Vessels					
Grain Movements			−0.029	−0.051	

Impulse Response Functions and Dynamic Multiplier Functions

Impulse response functions (IRF) and dynamic multiplier functions (DMF) are both post estimation techniques to graphically display the effects of a shock on a current equilibrium state. IRF measure the effect of a one standard deviation shock to an endogenous variable on itself or another endogenous variable while DMF functions relate a shock on an exogenous variable to an endogenous variable. As illustrated in Figure 4, each step in this analysis is a one week period indicating how long it takes the price in a segment to adjust to a shock. The vertical axis is in terms of barge rates and indicates the magnitude of the effect of the shock in each week and how long it takes the system to return to its previous state. With the Augmented Dickey Fuller tests rejecting the presence of a unit root at a 1% significance level, any shock effect will dissipate toward zero as the number of weeks approach infinity. Figure 4 illustrates the effect of a shock on the MTCT barge rate on the St. Louis segment and the effect of a shock on the Lower Ohio barge rate the Upper Ohio segment. The impact of a one standard deviation shock to the MTCT barge rate on the St. Louis barge rates takes over 30 weeks to fully dissipate. This is compared to the impact of a shock to the Lower Ohio barge rate on the Upper Ohio barge rates, which has a faster relative recovery time of approximately 15 weeks. The results illustrated in Figure 4, support the importance of the MTCT river segment on the rest of the inland waterway system. By reducing shocks to this system or increasing its allowable draft depth, positive benefits may be transferred upstream to the remaining segments.

Shock: MTCT Barge Rate → Response: St. Louis Barge Rate



Shock: Lower Ohio Barge Rate → Response: Upper Ohio Barge Rate

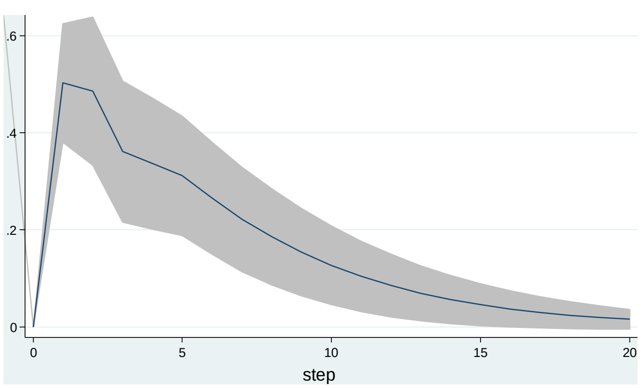
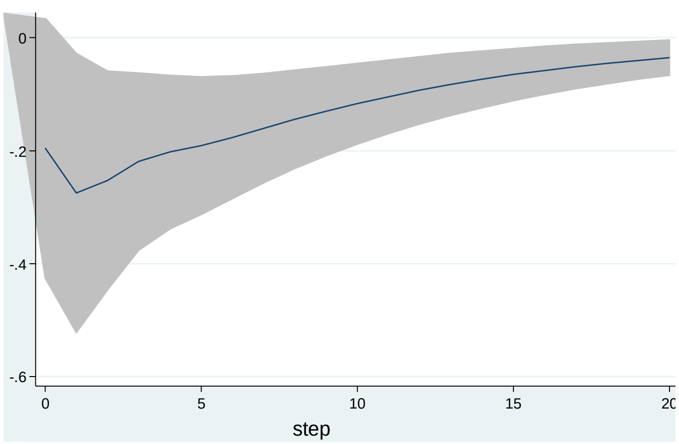


Figure 4. Impulse Response Functions of Barge Rates between Segments with a 95% confidence interval

Similarly, the DMF also support the MTCT segment importance. As illustrated in Figure 5, the impact of a unit increase in MTCT draft depth has a larger and longer lasting impact on barge rates than an increase in the Lower Ohio draft depths. This suggests projects attempting to improve barge rate efficiency should possibly focus on the MTCT draft depth. A one foot increase in the average draft depth of the MTCT would decrease barge rates by 3.50%, 1.27%, and 1.70% for the MTCT, Lower Ohio, and Upper Ohio segments, respectively. These results lay the foundation for future cost-benefit analysis on the economic viability of improving draft depth policies in select river segments.

Shock: MTCT Draft Depth → Response: St. Louis Barge Rates



Shock: Lower Ohio Draft Depth → Response: Upper Ohio Barge Rates

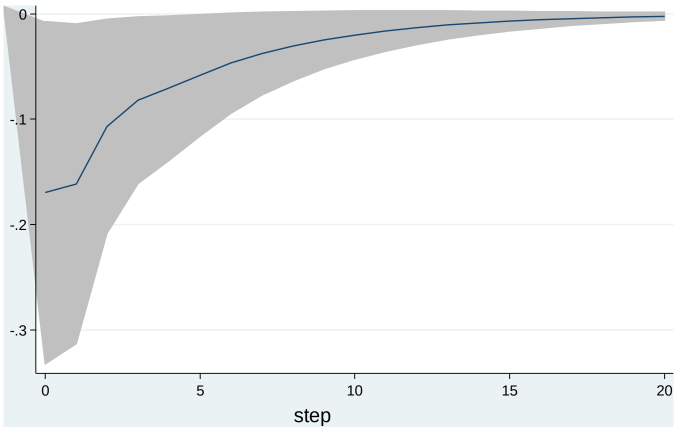


Figure 5. Dynamic multiplier functions of Draft Depths and Barge Rates among Segments

Policy Implications

Increased understanding concerning the interactions of barge draft depths and barge rates can have important consequences as the Mississippi allowable draft depth is directly controlled by the Army Corps of Engineers. Currently, federal law requires a Mississippi River shipping channel to be maintained at least nine feet deep and 300 feet wide. This has allowed the river to handle over 400 million tons of cargo annually, but this may not be enough to sustain increased demand for river transit (Fellin et al., 2001; U.S. Army Corps of Engineers, 2008). With expansion of the Panama Canal projected to reduce transportation costs to demand centers in Asia, the demand for agricultural goods transported on the Mississippi River is expected to increase.

As an initial investigation, an elementary cost-benefit analysis of maintaining a ten instead of a nine foot channel is evaluated. This simple analysis can serve as a pretext to a more exhaustive study. If the federal government were to change the mandated channel depth from nine to ten feet in the MTCT, St. Louis, Lower Ohio, and Upper Ohio River segments, the results of this analysis indicate barge rates on average would be reduced by 3.67% to 1.76% for these segments. This corresponds to a dollar per ton decrease in barge transportation of between $0.40

and $0.23 depending on the segment. The ranges of reduction in barge rates correspond to the high and low elasticity values over the five segments under study. Approximately half of the estimated 400 million annual tons handled by the river is covered hopper barges. Thus, if the mandated channel depth were to be increased to ten feet, there would roughly be an $80 million to $46 million decrease in annual transportation costs for covered hopper barges alone. This represents a lower bound on benefits with other river transportation vessels not included in the analysis also standing to improve efficiency from increased draft depth allowance.

In terms of dredging costs, the major costs are machinery and the labor of dredging crews along with external social and environmental costs. As estimated by the Army Corps of Engineers, these costs are $5.10 per cubic yard of material removed (U.S. Army Corps of Engineers, 2008). This is a one-time sunk cost and does not significantly impact the variable cost of continued dredging maintenance (Pociask, 2009). In terms of the social and environmental costs, this dredging cost includes compliance with the site-specific findings of the Great River Environmental Action Team (GREAT) (U.S. Army Corps of Engineers, 2010). This team revolutionized the management of the Mississippi River by adding focus on environmental impacts and sustainability. As a result, it is possible to reduce the environmental impact of increased dredging and in some instances, for a higher cost, it is possible to reduce them all together and provide a positive impact on the ecosystem.

Thus, as an initial rough estimate, the sunk cost of dredging the channel from nine to ten feet throughout the five segments is $468 million. The shipping channel is 300 feet wide and the length is 1564 miles, which requires the removal of 92 million cubic yards of sediment. Based on a 5% discount rate, it would take seven to fourteen years of transportation savings strictly from covered hopper barges to equal this $468 million dollar dredging investment. This payback period does not take into account the increased competiveness and comparative advantage that the United States may enjoy in international markets, nor the possible savings realized from other barge types and river transportation. Thus, a complete analysis would necessitate calculated elasticity values between draft depths and barge rates of other barge types as well as accounting for increased river transportation demand resulting from lower barge rates.

A further increase in dredging costs can provide long-run benefits to wildlife and the whole ecosystem in general. At an estimated additional cost of $6.41 per cubic yard of dredged material, over 49 square miles of wetlands and barrier islands have already been constructed (U.S. Army Corps of Engineers, 2010). The estimated 92 million cubic yards of dredged material could provide a great opportunity for ecosystem improvement by creating additional wetlands, barrier islands, and fish and bird habitats.

In the 2014 federal budget, $905 million was allocated for inland navigation with 90% of the budget assigned for lock and dam repairs and improvements and only 10% for dredging maintenance to maintain the current nine-foot channel depth (Fellin et al., 2001). Further, only $32 million annually is spend on new dredging projects or increasing the depth of existing channels while over $800 million is spent on existing lock and dam infrastructure. This spending disparity appears inconsistent with the results of this analysis. The estimated elasticity values of draft depth on barge rates are several times larger than the published elasticity values between lock delay times and barge rates.

There are several possible reasons for this spending disparity despite evidence that resources are not currently allocated in the most efficient way possible. When altering the physical characteristics of a natural resource, environmental repercussions are often an issue. There is still a strong negative environmental connotation associated with dredging the river, which has carried over prior to the creation of the GREAT. Furthermore, GREAT has led to complications in approving projects. Under GREAT, each small river section must be carefully studied and analyzed to provide maximum environmental protection (U.S. Fish and Wildlife Service, 1996). As a result, each individual Army Corps District is responsible for dredging its own stretch of the river and for developing new dredging proposals. Each district is responsible for the acquisition of funds, conducting environmental studies, and gaining authorization from Congress. This results in an intensive 12 step process to approve dredging work (Pociask, 2009) which is not present in lock and dam improvement or maintenance.

This lengthy and decentralized dredging approval process is in direct contrast to the approval of lock and dam repairs and improvements. There are less than 30 locks and dams in this five-segment region of the Mississippi, which greatly reduces the number of individual impact studies that must be carried out. Lock maintenance does not have the same environmental complications and negative connotations as dredging maintenance. Further, the headquarters of Army Corps of Engineers located in Washington, DC oversees all lock and dam work on the Mississippi.One central location manages multiple projects, which greatly simplifies the approval process (U.S. Fish and Wildlife Service, 1996).

Conclusions

Currently, the Army Corps maintain a nine foot deep and 300 foot wide navigable channel. The results indicate that draft depths significantly affect barge rates and that the magnitudes of the barge rate elasticities are larger than previous published lock delay elasticities. In contrast, only a small portion of the Army Corps' budget is spend on dredging, which suggests that policy and budget changes may improve efficiency. This analysis produces a dollar value for the cost to increase the channel depth one foot and examines the savings in transportation costs. However, there are also bureaucratic and environmental cost, which could prevent deeper dredging. The current decentralized management of the channel by river segment interferes with a comprehensive management plan. A central management system for river improvements would reduce the bureaucratic costs. The main environmental costs concerned with dredging the Mississippi are the placement of all the sediment removed from the river. The Great River Environmental Action Team has substantially reduced these environmental costs. The proper disposal of dredged material can play a vital role in future flood and storm protection; in addition to providing immediate benefits to the ecology and local wildlife. The estimated 92 million cubic yards of material that would have to be dredged to increase the channel depth from nine to ten feet could provide a great opportunity for improvement. With this improved understanding, the Corps' physical river management can be enhanced with programs directed toward dredging river segments with potentially greater reductions in price volatility.

This goal of improving the efficiency of barge transportation is especially pertinent with the expected 2016 completion of the Panama Canal expansion project. With the expansion, the cost to transport corn to China through the canal will decrease as much as $0.35/bushel. If the United States does not develop new methods to at least maintain or possibly reduce the cost of transporting an ever larger supply of commodities on the interior waterways, then the comparative advantage that domestic farmers enjoy today may be at risk. If this comparative advantage were to decrease, U.S. farmers could lose international market share to other agricultural export producing countries such as Brazil, Argentina, or Mexico who will also take advantage of the reduced cost to transport commodities through the Panama Canal. Thus, there is a real demand to improve efficiency of barge transportation on the Mississippi River. However, as the current literature on barge transportation efficiency indicates, there is little current economic evidence to support large scale lock infrastructure improvements to increase the efficiency of barge rates. Thus, further understanding of barge rate dynamics is especially critical to maintain our comparative advantage and international market share. Specifically, policy decisions regarding draft depth analysis may prove to be more cost effective then lock infrastructure improvements.

Footnotes

1. Similar results are were obtained for a fully constrained and unconstrained model. The downward bound model is presented as a representation.

References

Baumel C. 2008. “The Mississippi River System Shallow Draft Barge Market – Perfectly Competitive or Oligopolistic?” *Journal of the Transportation Research Forum* 47: 5-18.

Chi, J., B. Jungho. 2015. “Identifying the policy implications of barge shipments of grains on the U.S. inland waterway system: the case of corn movements on the Mississippi waterway,” Maritime Policy and Management 42(3-4):293-303.

Corps of Engineers. 2004. "History of the Mississippi River and Tributaries Project." K. Gibbs, ed., U.S. Army Corps of Engineers, New Orleans.

Corps of Engineers. 2010. “Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Midwest Region (Version 2.0).” Wetlands Regulatory Assistance Program. U.S. Army Corps of Engineers: Engineer Research and Development Center, August 2010. http://www.usace.army.mil/Portals/2/docs/civilworks/regulatory/reg_supp/erdc-el-tr-10-16.pdf

Edke, S. 2011. “The Economic Importance and Financial Challegenes of Recapitalizing the Nation’s Inland Waterways Transportation System,” National Corn Growers Association September 21, 2011. http://www.ncga.com/upload/files/documents/pdf/ebke_waterways_testimony_(t&i_hearing_9.21.11).pdf

Fellin L, Fuller S, Grant W, Smotek C. 2001. “Measuring Benefits from Inland Waterway Navigation Improvements.” *J Transp. Res. Forum* 40:113–136.

Fuller, S, W. Grant. 1993. “Effect of Lock Delay on Grain Marketing Costs: an Examination of the Upper Mississippi and Illinois Waterways.” *Logist. Transp. Rev* 29:81–95.

Gervais, J, T. Misawa, M. McVey, C. Baumel. 2001. “Evaluating the logistic and Economic Impacts of extending 600-Foot Locks on the Upper Mississippi River: a Linear Programming Approach.” *J Transp. Res. Forum* 40(4):83–103.

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

Miljkovic D, G. Price, R. Hauser, K. Algozin. 1999. “The Barge and Rail Freight Market for Export-Bound Grain Movement from Midwest to Mexican Gulf: An Econometric Analysis.” *Transportation Research Part E* 36:127-137.

National Academy of Science. 2001. “Inland Navigation System Planning: The Upper Mississippi River-Illinois Waterway.” National Academy Press. Washington DC. Pp. 130. http://www.nap.edu/read/10072/chapter/1

Pociask GE. 2009. “Annual Report for Active IDOT Wetland Compensation and Hydrologic Monitoring Sites.” Report submitted to the Illinois Department of Transportation, Bureau of Design and Environment, Wetlands Unit.

Sparger, A, N. Marathon. 2015. *Transportation of U.S. Grains: A Modal Share Analysis 1978-2013 Undate,* USDA Agricultural Marketing Service, June, 2015 http://www.ams.usda.gov/sites/default/files/media/ModalJune2015.pdf

U.S. Army Corps of Engineers. 2010. "Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Midwest Region (Version 2.0)." Wetlands Regulatory Assistance Program. Pp. 154.

U.S. Fish and Wildlife Service, Illinois Department of Natural Resources, and Illinois Natural History Survey. 1996. Illinois Wetlands Inventory, Vector digital data, Illinois Natural History Survey, Champaign, Illinois.

Yu, TH, D. Bessler, S. Fuller. (2006). "Effect of Lock Delay on grain Barge Rates: Examination of Upper Mississippi and Illinois Rivers." Ann. Reg. Sci. 40:887-908.