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Spatial Competition, Supply and Transportation Demand

A Study of Elevator Competition and Waterway Demands with Geographically Varying Elasticities and Spatial Autocorrelation

US Army Corps of Engineers®

IWR Report 05-NETS-R-09

Navigation Economic Technologies

The purpose of the Navigation Economic Technologies (NETS) research program is to develop a standardized and defensible suite of economic tools for navigation improvement evaluation. NETS addresses specific navigation economic evaluation and modeling issues that have been raised inside and outside the Corps and is responsive to our commitment to develop and use peer-reviewed tools, techniques and procedures as expressed in the Civil Works strategic plan. The new tools and techniques developed by the NETS research program are to be based on 1) reviews of economic theory, 2) current practices across the Corps (and elsewhere), 3) data needs and availability, and 4) peer recommendations.

The NETS research program has two focus points: expansion of the body of knowledge about the economics underlying uses of the waterways; and creation of a toolbox of practical planning models, methods and techniques that can be applied to a variety of situations.

Expanding the Body of Knowledge

NETS will strive to expand the available body of knowledge about core concepts underlying navigation economic models through the development of scientific papers and reports. For example, NETS will explore how the economic benefits of building new navigation projects are affected by market conditions and/or changes in shipper behaviors, particularly decisions to switch to non-water modes of transportation. The results of such studies will help Corps planners determine whether their economic models are based on realistic premises.

Creating a Planning Toolbox

The NETS research program will develop a series of practical tools and techniques that can be used by Corps navigation planners. The centerpiece of these efforts will be a suite of simulation models. The suite will include models for forecasting international and domestic traffic flows and how they may change with project improvements. It will also include a regional traffic routing model that identifies the annual quantities from each origin and the routes used to satisfy the forecasted demand at each destination. Finally, the suite will include a microscopic event model that generates and routes individual shipments through a system from commodity origin to destination to evaluate non-structural and reliability based measures.

This suite of economic models will enable Corps planners across the country to develop consistent, accurate, useful and comparable analyses regarding the likely impact of changes to navigation infrastructure or systems.

NETS research has been accomplished by a team of academicians, contractors and Corps employees in consultation with other Federal agencies, including the US DOT and USDA; and the Corps Planning Centers of Expertise for Inland and Deep Draft Navigation.

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A Study of Elevator Competition and Waterway Demands with Geographically Varying Elasticities

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Spatial Competition, Supply and Transportation Demand

A Study of
Elevator Competition and Waterway Demands
with
Geographically Varying Elasticities and Spatial Autocorrelation[†]

by

Kevin E. Henrickson[*]

September 2005

Abstract

In this study, I develop and estimate a model of spatial competition between grain elevators. Grain elevators compete over space for products, which they in turn supply to the market and form the demand for transportation. I model these supply and corresponding transportation demands as as a function of prices, transportation rates and a variety of control variables. These control variables capture the spatial environment from which decisions are made. Further, elevators operate in different geographic areas with differing market and demand alternatives which imply structural breaks across regions. A variety of models designed to capture geographic differences in the elasticity parameter are employed to uncover structural breaks in the data along the geography of the network. Further, these elevators compete with each other spatially, with the result that their errors may be spatially correlated. To examine this possibility, I estimate a spatial autocorrelation model for the potential spatial clustering of errors. The results suggest that demand elasticities vary across the spatial environment, and that the presence of competitors can and does have a sizable impact on the structure of demand. These results are of central importance to policy-makers as they call into question the assumptions made by models currently in use for measuring the benefits of inland waterway improvements, and yet, provide estimates that are easily adapted to the models used to measure these benefits.

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1. Introduction

Economists have long recognized the importance of space in modeling economic relationships.[1] Most of this work has been theoretical in nature, and until recently, there is very little empirical modeling of these relationships.[2] In this study, I develop an empirically tractable model of spatial competition between grain elevators located on the inland waterway system, and their resulting barge transportation demand. The inland waterway system, on which these elevators are located, is of critical importance to the U.S. economy as it provides access to export/import markets from the interior of the country. However, much of the infrastructure of the inland waterway system is antiquated and in need of updating, a job which falls to the U.S. Army Corps of Engineers (ACE). In conducting benefit-cost analyses of proposed waterway improvements, ACE has used a suite of models whose foundations and assumptions have been evaluated and criticized by the National Research Council (NRC) of the National Academy of Sciences (NRC, 2001).

The model developed in this study, grounded in spatial competition, both fits directly into current ACE planning models, and overcomes many of the shortcomings identified by the NRC and others. I empirically apply this model to interview data collected by the Tennessee Valley Authority (TVA). In so doing, I use multiple techniques to examine the geographic pattern of barge demands using a variety of control variables which include measures of the spatial environment over which decisions are

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[1] Two of the most common topics in the spatial economics literature are the size and shape of firms' market areas (e.g. Clark and Clark (1912), Fetter (1924), Lösch (1954), Mills and Lav (1964), and Eaton and Lipsey (1976)) and spatial pricing/competition (e.g. Hotelling (1929), Lerner and Singer (1937), Smithies (1941), D'Aspremont, Gabszewicz and Thisse (1979), Fujita and Thisse (1986), and Anderson, de Palma and Thisse (1989)).

[2] See Inaba and Wallace (1989) as an example of both a theoretical model, and empirical examination of transportation demand over space.

made. The results suggest that barge demand elasticities vary geographically, and are relatively elastic. Further, since grain elevators compete spatially for their products, and since their decisions are made in a highly competitive market, I estimate a spatial autocorrelation model as a robustness check for the potential spatial clustering of errors.

There are a number of transportation demand studies. In these studies there is a wide range of how the models are formulated and estimated.[3] There are two general classes delineated along aggregate and disaggregate dimensions. Aggregate demand models reflect aggregations of shipments. The aggregation can be over shippers, commodities, or shipments of particular shippers of a given commodity. Disaggregate demand modeling reflect examinations of individual shipments and the associated mode and/or market decisions from a set of alternatives. Baumol and Vinod (1970) estimate an inventory based model where the choice of mode is integrated with other production decisions. Also using individual shipment data, McFadden (1973), Daughety and Inaba (1973) and Winston (1981), Inaba and Wallace (1989), Abdelwahab and Sargious (1992) and Abdelwahab (1998) estimate transportation demand using random utility methodology.

[3] Within this literature many different forms of transportation demand have been analyzed for the various modes. For automobile usage, Mannering and Winston (1985), Hensher, Milthorpe and Smith (1990) among others find that demand is relatively inelastic. Similar results are found for urban transit demand (e.g. De Rus (1990)). Studies on the transportation demand for air passenger travel find a wide range of elasticity estimates. The literature on air passenger travel also finds evidence that the demand elasticity varies for the different fare classes (e.g. Oum, Gillen and Noble (1986) and Straszheim (1978)). Still other studies use discrete choice models to estimate travel demand elaticities (e.g. McFadden (1974)). Of more relevance for the topic at hand are the studies examining the demand for freight transportation, either rail (e.g. Boyer (1977), Wilson, Wilson and Koo (1988) and Winston (1981)) or truck (e.g. Friedlaender and Spady (1980), Wilson, Wilson and Koo (1988) and Winston (1981)). For a more complete treatment of transportation demand studies, see Oum et al. (1992).

Until recently, there have been relatively few studies of transportation demand that include barge transportation.[4] The controversy surrounding the NRC, however, has spurned considerable activity in the area. For example, a recent study by Train and Wilson (2005a) uses both revealed and stated preference data to analyze both mode and origin-destination changes as a result of a change in the barge rate. Using this framework they estimate barge demand elasticities between -.7 and -1.4, results similar to those found in this study.[5]

The present study adds to this literature by estimating a shipper disaggregated model of barge transportation demand, which is used to estimate the elasticity of barge transportation demand for elevators located along the Upper Mississippi and Illinois rivers shipping grain products, paying specific attention to the spatial nature of transportation demand.[6] In particular, I employ both rolling and locally weighted regression techniques as well as interaction terms and endogenous switch points to examine patterns in barge demand elasticity across a geographic space. The results of these methodological approaches indicate that barge demand elasticity varies geographically across the river with elasticity estimates ranging from -1.350 and -1.987. As a robustness check, a spatial autocorrelation model is estimated to examine the

[4] With the most notable exception being Inaba and Wallace (1989) which uses self selectivity models to estimate transportation demand, including barge transportation demand, over geographic space.

[5] Other recent studies of barge demand elasticity include: Sitchinava, Wilson and Burton (2005) who use stated preference responses to study barge transportation demand on the Ohio river, finding that demands are elastic, but vary greatly across commodities and shippers; Train and Wilson (2005b) who use stated and revealed choice data on shippers in the Pacific Northwest, find that barge demand in this region is relatively inelastic and that the distance to the waterway is a significant factor in the decision to use the waterway; Dager, Bray, Murphree and Leibrock (2005) find relatively inelastic barge demand for corn shipments on both the Illinois and Mississippi rivers; and Yu and Fuller (2003) find relatively inelastic, though often insignificant, elasticity estimates for the Illinois and Mississippi waterways.

[6] Note that the focus of this study is on grain products as they are the most common commodity being shipped on the Upper Mississippi and Illinois rivers, with corn being the dominant commodity within the group. Also worth noting is that, by incorporating the spatial nature of transportation demand, this study addresses one of the NRC's other criticisms of the current ACE planning models (NRC, 2004).

possibility of geographically clustered error terms; however, tests for the appropriateness of this model indicate that the error terms of elevators are not spatially autocorrelated, which implies that the regional competition variables included in the model specification capture the local competitive environment of grain elevators located on the Upper Mississippi and Illinois Rivers.

The elasticity results found in this study directly call into questions the assumptions made by current planning models used by ACE, while also providing a contribution to the spatial modeling of demand models. The ACE models, used to calculate the estimated benefits of inland waterway improvements, have recently been the source of both controversy and criticism (NRC, 2004). Specifically, these models either assume that barge demand is perfectly inelastic or that demand is less than perfectly inelastic, but that this elasticity can be specified by the user rather than being empirically estimated. This study indicates that the assumption of perfectly inelastic demand in these models is at best questionable, and additionally, provides a methodology which fits directly into the current ACE planning models, and addresses many of the concerts expressed by the NRC.

The remained of this study is divided into 5 sections. Section 2 develops a theoretical model of spatial competition between grain elevators located along the waterway system. Section 3 outlines numerous empirical strategies of estimating the demand for barge transportation stemming from the theoretical model developed in Section 2. Section 4, outlines the data and variables used for the analysis. Section 5 presents the results of the various empirical specifications, while in Section 6 provides concluding comments.

2. Theoretical Model

This study is primarily focused on the transport of agricultural products along the Mississippi and Illinois rivers. The transportation of agricultural products is a key element of agricultural markets. When harvested, these agricultural goods are generally transported from the farm to one of three places: a storage facility, a gathering point where goods are sold and then shipped elsewhere, or to a final destination. The focus here is on the gathering points that include country elevators, rail sub-terminals, and/or barge loading facilities. While storage facilities and final destination points represent alternatives, almost all agricultural commodities are moved through at least one of these gathering points on its way to its final destination which may include export markets, processing plants and feedlots.[7] The data used in this study, described in detail later, represent the transportation decisions of barge loading facilities located along the Mississippi and Illinois rivers. These facilities receive agricultural commodities from farms or other gathering points, and then ship these commodities to another point in the transportation infrastructure.

The theoretical model developed here is a model of competition between grain elevators. This model shows that an elevator's profit maximizing quantity and resulting market area are a function of firm characteristics, characteristics of its rivals and the space that they are competing in. Compared to other modes of transportation, modeling competition between grain elevators located along the Mississippi and Illinois rivers allows for the simplification of modeling elevators as being located in a linear geographic

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[7] The focus of this work is on US shipments. As such, the export market is deemed a "final" destination. Obviously, once at the export elevator, there is another set of transportation and marketing decisions; however, this complication is avoided by considering the export market a final destination as the decisions made at this stage of the transportation process are beyond the scope of this study.

space.[8] Specifically, assume that there are $n=1,2,\ldots,N$ elevators located along the river from highest point on the river to lowest point on the river. Further assume that these elevators are located $D=d_{1,2,}d_{2,3},\ldots,d_{n-1,n}$ miles apart from one another, and that grain production per mile is distributed between elevators with parameter *y*.[9]

Assuming profit maximizing behavior, farmers sell their grain to the elevator *e* which yields them highest returns net of transportation costs $(w^e + \delta_e - \theta D^e)$ where w^e is elevator *e*'s bid price, δ_e is the farmer's preferences for elevator *e*, θ is the farmer's cost per unit distance, and D^e is the distance from the farmer's location to elevator *e*.[10] The farmer's problem then is a decision of where to sell their crops to from a set of locations, which are translated into distances for the current application.[11]

Given farmer's decision making rule given above, consider farmers producing grain who are located between two elevators generically defined as elevator A and elevator B, located *D* miles apart. The farmer who is indifferent between these two elevators is located at a point such that:

$$D^A = \frac{w^A - w^B}{2\theta} + \frac{\delta_A - \delta_B}{2\theta} + \frac{D}{2} \quad (1)$$

Notice that D^A not only gives the distance of the indifferent farmer from elevator A, but also indicates the share of the market captured by elevator A, i.e. the market areas of elevators A and B. According to equation [1], the distance the indifferent farmer is

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[8] However, this model is general enough to be adapted to non-linear distances.

[9] Note that this assumes that grain is evenly distributed between elevators; however, this model is again general enough to be adapted to a non-even distribution of grain.

[10] δ_e enters this equation to control for non-price differences across farmer's utility functions. For example, one farmer may like the options provided to it by using a large multi-plant companies elevators, while a different farmer may prefer his/her local cooperative elevator to the large corporative elevators.

[11] It is assumed that no one elevator offers a price high enough to price the other elevators out of the market.

from elevator A, D^A, is increasing in the price elevator A offers, $\frac{\partial D^A}{\partial w^A} > 0$, decreasing in the price elevator B offers, $\frac{\partial D^A}{\partial w^B} < 0$, increasing in farmer tastes for elevator A, $\frac{\partial D^A}{\partial \delta_A}$, decreasing in farmer tastes for elevator B, $\frac{\partial D^A}{\partial \delta_B}$, increasing in the distance between the two elevators, $\frac{\partial D^A}{\partial D} > 0$ and ambiguous in the farmer's transportation cost, θ.

While equation [1] describes elevator A's market share, i.e. market area, when competing with elevator B, elevator A also competes with an additional elevator which is located on the other side of elevator A. Put more concretely, these elevators are located linearly along a river implying that each elevator has competitors both up- and downriver from its location. Given this, elevator A's total output is given by the total product produced (*yD*), and its share of the distance between elevator B on one side and elevator C on the other, which are denoted D^{A-B} and D^{A-C} as defined by (1). Mathematically, this means that the total output for elevator A is given by:

$$\begin{aligned} Q^A &= Dy\left\{ \int_0^{D^{A-B}} \frac{1}{D} dt_1 + \int_0^{D^{A-C}} \frac{1}{D} dt_2 \right\} = Dy\left\{ \frac{D^{A-B}}{D} + \frac{D^{A-C}}{D} \right\} \\ &= \frac{y}{2\theta}\left\{ 2w^A - w^B - w^C + 2\delta_A - \delta_B - \delta_C \right\} + \frac{Dy}{2} \end{aligned} \tag{2}$$

According to equation [2], elevator A's output is increasing in the price it offers, but decreasing in the price of its rivals. Further notice that if prices and non-price characteristics are the same, the elevators simply split the market area. If prices are different, then there are a number of effects. First, greater distances between elevators increase total regional output and, hence, the quantity each elevator handles. Second, an increase in farmer transportation costs reduces the effectiveness of pricing differences on the market area, and therefore, the quantity of the higher priced elevator. Of course, since all goods are shipped, it has the effect of increasing the quantity of the lower priced elevator. Finally, as with increases in the distances between elevators, increases in the grain yield result in a larger total market with no change in market area resulting in an increase in production at each elevator. Third, an increase in farmer preferences for elevator A relative to elevators B and C, leads to an increase in elevator A's output.

Equation [2] defines the output of a representative elevator that competes with others over geographic space and provides a deterministic relationship within the model, i.e. there is a unique w^A for a corresponding output level (Q). For the purposes of this paper, it is convenient to invert equation [2] to provide the "bid" price of an elevator as a function of output. The bid price is then given by:

$$w^A = \frac{1}{2}\left\{w^B + \delta_B + w^C + \delta_C\right\} + \frac{\theta}{y}\left\{Q^A - \frac{Dy}{2}\right\} - \delta_A \qquad (3)$$

The costs of gathering output through a bid price provide for the costs the elevator incurs to procure the grain for shipments. The costs of procurement are simply the bid-price multiplied by the quantities attracted to the elevator's location. These costs are given by:

$$\begin{aligned} \mathrm{C}^{\mathrm{Procurement}} &= w^A Q^A = w^A(Q^A, w^B, w^C, D, y, \delta_A, \delta_B, \delta_C)Q^A \\ &= C^{\mathrm{Pr}ocurement}(Q^A, w^B, w^C, D, y, \delta_A, \delta_B, \delta_C) \end{aligned} \qquad (4)$$

with the properties that marginal costs are positive and increasing in Q.

An elevator with procurement costs given by [4] has additional operating costs which are assumed to be positively related to elevator activity levels (Q), factor prices (z), and non-positively related to fixed asset levels (e.g., capacity, K). That is, $C^{\text{Operations}} = C^{\text{Operations}}(Q^A, z, K)$. Having defined the individual components of elevator costs, the total cost function of a facility making transportation decisions, is given by:

$$\begin{aligned} C^{\text{Elevator}} &= C^{\text{Operations}}(Q^A, z, K) + C^{\text{Procurement}}(Q^A, w^B, w^C, D, y, \delta_A, \delta_B, \delta_C) \\ &= C(Q^A, z, K, w^B, w^C, D, y, \delta_A, \delta_B, \delta_C) \end{aligned} \tag{5}$$

Note that the cost function defined by equation [5] includes the bid prices of the firm's rivals. This is not a common treatment of the cost function of shippers, and arises because the model developed here explicitly accounts for the geographic space over which the elevators are competing. However, as long as this cost function has increasing marginal costs, the remainder of the theory applies.

Further notice that for the procurement cost function to be increasing in output is that there is less than a direct matching of price changes by competing elevators, which would lead to no change in quantity.[12] However, the assumption of differentiated services, i.e. farmer preferences over elevators and other elevator attributes which vary including yields, capacity levels, transportation attributes, etc. allow for a non-trivial result.

Given the cost structure derived in equation [5], the firm chooses quantity, Q^A, which implicitly determines w^A given the bid prices, and preferences for its rivals by solving its profit maximization problem:

$$Max\ \pi \ = \ (P - t - s)Q \text{ - } C(Q) \tag{6}$$

where P is the price that the elevator gets for the commodity, t is the transportation costs associated with shipping the commodity, and s is the service characteristics of the

[12] This can be seen by totally differentiating equation [2] and imposing the restriction that price changes are equivalent.

shipment. The solution to the firm's maximization problem represented by equation [6] gives the quantity that the elevator will ship, assuming that larger shipment sizes are harder to procure. There are many ways that the assumption of larger shipments being more difficult to procure can be satisfied; for example, the shipper having to increase its bid prices in order to increase its gathering area or to induce farmers to reach a reservation price. Theoretically, the grain elevator's profit maximizing profit level given by the solution to equation [6] is a function of the price the elevator receives, the transportation rate, service induced costs, and procurement/processing costs determinants:

$$Q^* = Q^*(P, t, s, c, D, y) \tag{7}$$

where c is the set of parameters from the cost function previously derived in equation [5].

Given the first-order condition to equation [6], one can derive comparative statistics for how changes in each of the elements of equation [7] affect the firm's profit maximizing choice of quantity (market area). Increases in P, the price that the elevator receives, the grain per mile produced (y), and the distance between elevators (D) will not decrease the quantity, or market area, of the firm. Alternatively, increases in t or c will not increase the quantity, or market area, of the firm. As for how the individual elements of elements of c, the cost parameter, impact the firm's profit maximizing quantity, increases in factor prices (z) and the bid prices of rivals (w^A and w^B) increase costs, thus reducing both profits and the firm's quantity, or market area, while increases in capacity (K), grain per mile (y) and distance between elevators (D) reduce costs therefore, increasing both profits and the firm's quantity, or market area.

3. Empirical Methodology

Theoretically, the profit maximizing quantity shipped by an elevator was found to be a function of the price that the elevator gets when it ships the commodity, transportation costs of shipping the commodity, the service characteristics of the mode of transportation, the costs of operation, farmer preferences for non-price characteristics of the elevators, crop production, and the distance to competitors. In this section, an empirical model is developed to estimate these relationships.

As noted previously, and discussed in greater detail later, many of the elevators in our sample of data tend to cluster at different points along the river. I model the farmers' decisions as sequential. That is, they first choose a particular cluster of elevators and then choose the specific elevator within a given cluster. In the first case, farmers choose between groups of elevators, and, given the group chosen, farmers choose the specific elevator. The first case is likely generated by geographic space as well as differences in the bid prices. The second case is generated by prices as well as non-price factors. This structure is useful in empirical modeling in that there are a number of cases wherein elevators within a group are extremely close to one another, yet the groups may be some distance away. To account for each of these types of competition, several measures of spatial characteristics are added to equation [7]. These spatial measures are intended to capture both the magnitude of competition and include: the number of firms in the area and the capacity of competing elevators in the area.

Thus far, competition from non-river facilities has been ignored; however, competition from these locations needs to be accounted for in the empirical specification as its intensity is likely to vary along the river. While the output of these non-river facilities is not observed in the data, information on the alternative transportation rate (non-barge rate) for the river terminals is observed, and is added to equation [7] in order to control for competition from off-river facilities.[13] It is also noted that due to geography, or perhaps specialization, elevators' annual output may be comprised of different compositions of grain products (e.g. corn, wheat, soybeans). Because corn is the dominant crop produced in the United States, firms shipping almost exclusively corn should have higher annual ton-miles than firms shipping little to no corn.[14] This is accounted for by adding a variable capturing the proportion of elevator shipments that are composed of corn to equation [7]. Finally, it is noted that there are two general classifications of firms: large conglomerate firms with many locations and independent or cooperative local firms. Any preferences that farmer's may have over these types of firms enters into equation [7] through their non-price preferences, δ. Therefore, a dummy variable for conglomerate firms is added to equation [7] to control for each of these types of firms. Empirically, based on equation [7], and the aforementioned observations, the base model to be estimate is given by:

Annual Ton-Miles = *f* (barge rate, alternative rate, transportation rate from farmer to elevator, distance to nearest competitor, firm capacity, number of firms in the area, capacity of competing firms in the area, dummy variable for large conglomerate firms, area production, % of elevator shipments that are corn) (8)

Where *barge rate* is the rate per ton-mile of the barge movement; *transportation rate from farmer to elevator* is the rate per ton-mile of transporting the commodities, via truck or rail, to the barge loading facility (i.e., in the context of the model presented earlier, it is the farmer's transportation cost); *alternative rate* is the rate per ton-mile of

[13] This is done because the alternative rate (e.g. rail and/or truck) facing the river terminal is likely to be the same as the rate facing non-river elevators.
[14] According to the USDA, corn production in 2000 was almost exactly twice the combined sum of wheat and soybeans.

the most common alternative to shipping down the river, an element of mode choice from our theoretical section; *distance to nearest competitor* is the distance to the nearest competitor; *capacity* is the capacity in bushels of the firm; *number of firms in area* in the number of competing elevators in the same pool; *capacity of firms in area* is the capacity of the firms in the same pool; *area production* is the average production of the commodity in the elevator's county and bordering counties; *% of elevator shipments that are corn* is the proportion of total shipments that are corn; and the *dummy variable for large conglomerate firms* is a dummy variable equal to 1 if the shipper is one of the six conglomerate firms in the sample. [15]

Equation [8] is specified in a double log form and estimated using both ordinary least squares (OLS) and a fixed effects model (FE). The fixed effects model allows the intercept of equation [8] to vary by "pool" along the river. A pool is a body of water between two fixed points. In this case, a pool is the body of water between two locks.[16] The purpose of the fixed effects specification in this context is to capture any unobserved differences in pools that influences elevator output, but which is unobserved in the data.

In equation [8], the effect of increases in both the barge rate (the law of demand) and the transportation rate (θ in our theory) are expected to be negative. It is also expected that an increase in the distance to the nearest competitor (*D* from our theory) will increase annual tonnages. Capacity should also increase production, the number of firms in the area has an ambiguous effect (it increases competition which should decrease quantity, but farmers from far distances are more likely to ship to an area where there are

[15] A pool is the area between two locks on the river.
[16] In Army Corps of Engineer modeling efforts, demands are typically defined at the pool level. That is, they consider the originating-terminating and commodity triple as a demand function that enters into their planning models.

many choices and then choose which to use when they arrive), the capacity of the firms in the area is predicted to have a negative effect because larger firms in the area means stronger competition, and area production (*y* from our theory) should have a positive effect.

Recognizing that these data represent grain elevators located over a vast geographic space, rolling regressions and locally weighted regressions techniques are used along with parametric interaction terms and endogenous switch points to examine the geographic patterns of barge demand elasticity. Additionally, as a robustness check, a model of spatial autocorrelation is estimated to allow for the possible spatial clustering of errors. For expedience, each of these models is discussed in detail below with a description of the results.

4. Data

The data used in this study contain information on river port elevators. These data were obtained from the Tennessee Valley Authority (TVA) who, during two sets of personal interviews of barge terminals located along American's inland waterways, collected information regarding each elevator's annual tons shipped, commodities shipped, barge charges, truck transfer charges, the termination of the shipments, average gathering area of product to be shipped, alternative routes that they could have sent that shipment if not by barge, and various other firm characteristics. A subset of these data is employed for this analysis. In particular, the activities of the 103 grain elevators located on the Upper Mississippi and Illinois rivers are examined.

Figure 1 visually depicts these 103 elevators.[17] Unlike many previous theories of spatial competition assume, these elevators are not uniformly distributed along the

[17] The TVA data were matched with the USACE Port Series database to obtain these terminal locations.

waterway system. Instead, there are large groupings, or clusters, of firms at some locations and single elevators elsewhere. One explanation for this clustering of firms lies in differences in crop production along various stretches of the river. Alternatively, river characteristics, such as the location of locks along the river, rail connection points, land prices, and appropriateness of the land for elevator operations, etc., may also have influenced the location of firms.

The data also provide for the average distance goods travel to the facility before being loaded to barge. This is the "gathering area" of the elevator. Figure 2 shows the median gathering areas for groupings of firms. These gathering areas were calculated by first grouping the elevators together according to their location along the river and then calculating the median gathering area of the elevators in each grouping. These median gathering areas were then graphed in the center of the geographic group.

Variables

From equation [8], the dependent variable for this study is *annual ton-miles* which is defined as the annual-tons shipped multiplied by the distance of the shipments.[18] The right-hand side variables include: the *barge rate* defined as the barge charge per ton divided by the miles of the movement; the rate *transportation rate from farmer to elevator* is defined as the transportation rate per ton, via truck or rail, to the barge loading facility divided by the miles transported to the elevator; *alternative rate* is the rail, truck and/or barge rate per ton-mile of the next best alternative to shipping down the river; *distance to nearest competitor* is the distance, in miles, to the nearest competitor either

[18] Tonmiles is the traditional measure of output in the transportation literature. An alternative output measure is tonnage; however, transportation occurs over space, and one ton moved ten miles is much different then one ton moved 1000 miles.

up-steam or down-steam; *capacity* is the capacity in bushels of the firm; *number of firms in area* in the number of competing elevators in the same pool; *capacity of firms in area* is the capacity of the firms in the same pool minus the elevator's own capacity; *area production* is taken from the USDA's county level crop output database, and is defined as the average production of the commodity being shipped in the elevator's county and bordering counties; *% of shipments that are corn* is defined as the number of annual corn shipments divided by the total number of shipments; and the *dummy variable for large conglomerate firms* is a dummy variable equal to 1 if the shipper is one of the six conglomerate firms in the sample. Summary statistics for each of these variables along with the reported gathering area of the elevators are provided in Table 1. For this study, all variables (except for the distance to the nearest competitor, the number of firms in the area, the % of shipments that are corn and the conglomerate dummy variable) are estimated in logs.[19]

These descriptive statistics provided in Table 1 suggest that there is considerable variation in annual ton-miles shipped. That barge rate per ton-mile is much smaller than the alternative rates (rail and truck), and that rates from the farmer to the elevator are approximately 7 times higher than the barge rates, but much less than the alternative rate, owing to shorter distances. Firm capacity and area capacity vary quite a bit from elevator to elevator. The distance between elevators is about 2.5 to 7.7 miles, while the number of firms in the same area appears to be approximately 5. There also appears to be considerable variation in the area production of crops. Finally, the gathering area (the distance of inbound shipments) has a median value of 60 miles and an average value of about 71.1. Further, a simple regression of gathering area and river mile indicates that

[19] These variables are not estimated in logs because they take values of zero.

gathering areas increase with river mile, and a 100 mile increase in river mile increases gathering areas about 4 miles. From the lower reaches of the river to the most northern areas, this suggests a difference in gathering area of approximately 33 miles.[20]

5. Results

Table 2 presents the results of running the base model specified by equation [8] using both OLS and fixed effects. The first two columns of results are from the OLS specification (with and without the observable regional characteristics variables), while columns 3 and 4 are from the fixed effects specification. While the fixed effects models fit the data better with r-square values of .5 and .53 versus .36 and .4, tests for the appropriateness of the fixed effects conclude that they are not warranted at any standard level of significance.

The estimated elasticity of barge demand is negative and significant in all four models with fairly similar estimates of: -1.414 (OLS without spatial controls), -1.614 (OLS with spatial controls), -1.508 (fixed effects without spatial controls), and -1.799 (fixed effects with spatial controls). The transportation rate from the farmer to the elevator (θ from the theoretical model) is also negative and significant in all models indicating that as the cost of transporting crops to the river elevators increase, the quantity shipped by the elevator decreases as was predicted by the theoretical model. Area production, y in the theoretical model, is positive and significant in both of the spatial control models indicating that as the crop production in the elevators' county and neighboring counties increases, the river elevators ship more. The percent of shipments that are corn is also positive and significant across all specifications indicating that firms

[20] Anderson and Wilson (2004) theoretically show that this should be the case, as farmers are willing to transport a further distance to the river in order to take advantage of the relatively cheaper barge transportation as the distance to be traveled increases.

who specialize in corn shipments, whether it be because of geography or specialization, ship more annual ton-miles of corn. The estimated coefficients on capacity and the conglomerate dummy variable are both positive across all specification; however, the effect of capacity is only significant in the OLS spatial control specification and the effect of the conglomerate dummy is only significant in the OLS specifications.[21] These results indicate that elevators that are part of large national conglomerate firms and firms with higher capacity levels ship more annual ton-miles. Note that in the spatial control fixed effects model the effect of the number of firms in the pool is not estimated as it does not vary within the pool. All other variables from equation [8] are statistically insignificant across all specifications.

Geographically Varying Elasticity Estimates

All specifications in the base model presented in Table 2 restrict the elasticity of barge demand to be constant across all observations. However, given that the alternatives confronted by spatially distributed river facilities differ, the constant elasticity assumption may not be appropriate. To see this point, recall from the theoretical section that grain elevators procure their commodities from farmers. To the extent that farmer's have different shipping options at different locations along the river, the effect of changes in the barge rate on the quantity shipped, i.e. the elasticity of barge demand, may vary along the river. For example, a farmer with no rail service or nearby country elevators may respond to a decrease in the bid price of an elevator (equivalent to an increase in the barge rate faced by the elevator) by not changing their quantity supplied. Alternatively, a farmer who is either close to other river elevators or is close to a country elevator with rail service to an alternative destination market (e.g. the Pacific Northwest) may respond

[21] The effect of these variables may be captured in the fixed effect coefficients.

to the lower bid price (higher barge rate) by sending all crops to a different facility. Therefore, theoretically, barge demand elasticity may vary along the river. However, the exact form of this variability is unknown prior to estimation.

As an initial examination of the pattern of geographic barge demand elasticity, rolling regressions and locally weighted regressions techniques are employed. In each of these models, the data are ordered in ascending order according to river mile. The model given by equation [8] is then run on subsets of the data, with the difference between the two models being how the subset is used in the estimation process.

Rolling regressions were first developed by Fama and MacBeth (1973) and Officer (1973) to study time series data. These models were developed to see how the same relationship changed over time; however, the same methodology can be employed over geographic space where there is a natural ordering to the spatial variable. In this case, the location of the elevators is available according to river mile (miles from a point on the river). This measure then provides a natural ordering which is then used to apply the rolling regression methodology. The result allows an empirical representation of how transportation demands vary over geographic space. In the rolling regressions model, the estimation equation, as specified above in equation [8], is run on a user specified "window" of data.[22] In practice, the barge demand equation is run on the first x observations (geographically) and the demand elasticity is recorded, where x is the specified window size. Note that x is arbitrarily chosen, and the only restriction on it is that it must be large enough to estimate the equation. The barge demand equation is then run on observations 2 through $x+1$ and the estimated demand elasticity from this equation is recorded. The equation is then run on 3 through $x+2$, 4 through $x+3$, etc. In essence, a

[22] The size of the window (x) is arbitrary, and thus various specifications of the window size are run.

window of size *x* is moved along the river one position at a time estimating the demand elasticity for each window location.

The second technique used in this study to examine barge demand elasticity over space is the locally weighted regressions model developed by Cleveland (1979). This technique is similar to the rolling window technique just described with one notable difference. As with rolling regressions, the locally weighted regressions procedure also requires the econometrician to specify a window size over which the demand equation is estimated and, again, the window moves up the river one position at a time. The key difference is that the observations in the window are weighted such that the middle position gets the highest weight and each position away from the middle gets subsequently lower weights. For example, if a window size of 5 was specified, the middle position would be the 3rd observation in the window and it would receive a weight of 1, indicating that it is fully weighted. Positions 2 and 4 would receive a weight of .89 each, positions 1 and 5 would receive a weight of .35 each, and positions 0 and 6 would receive a weight of 0 meaning that they are not included in the regression. Note that this weighting scheme is the tricube weight proposed by Cleveland *(9)*. Weighted least squares is then used to estimate the demand elasticity for the given middle location and window size. The estimated elasticity is then recorded and the window is moved up the river one location and estimated again. This procedure is designed to give a more "localized picture" of the estimated barge demand elasticity at any given point along the river.

Figures 3 and 4 provide a graphical representation of the results for a window size of 40 (x = 40) for the rolling regressions technique and the locally weighted regressions model respectively. Because of the sample size of the data used is relatively small, the elasticity results are not "precisely measured", but the patterns bear a strong resemblance and are used to specify parametric forms below. Generally, elasticities tend to be higher in magnitude in the southern and extreme northern parts of the river, and lower in magnitude (relatively, more inelastic) in the middle section of the river.

This pattern of geographic elasticity arises because of several distinct features of the river system. First, farmers and country elevators located on the southern reaches of the river system, have the shortest distance to be traveled by river, and therefore may either use a different mode of transportation, or bypass the lock system by putting their commodities on the river at a more southern point. As for the northern segments of the river, which are also more responsive to barge rates, the inverse pricing rules employed by railroad companies in Minnesota and North Dakota will tend to increase the alternatives of farmers and country elevators in this region as shipping to the Pacific Northwest via rail becomes more feasible, which also increases the elasticity of barge demand in this region. Finally, shippers located towards the central portions of the river system have long distances to travel via any mode, and therefore, with fewer options available, are less responsive to changes in the barge rate.

In addition to the two approaches just described, two parametric models are used to estimate geographically varying barge demand elasticity. The first parametric approach used is the interaction of barge rate with river mile and various higher degree polynomials of river mile in an attempt to capture the relevant systematic patterns along each river. The results of this technique are presented in Table 3, Figure 5 for the Upper Mississippi River, and Figure 6 for the Illinois River. This parametric approach to estimating geographically varying elasticity estimates has the advantage of allowing the exact form of elasticity to be flexibly estimated rather than user imposed. However, using interaction terms has the disadvantage of forcing elasticity to vary *systematically* along the river. The results of these models indicate that the same pattern of elasticity exists for both the Upper Mississippi and Illinois rivers. Specifically, Figures 5 and 6 suggest that barge demand elasticities are relatively more elastic on both the southern and northern ends of the rivers, while elasticity is relatively more inelastic towards the center.

In all cases, the rolling, weighted and varying coefficient models provide relatively wide ranges of elasticity that depend on the spatial location of shippers on the river. In all cases, the pattern is relatively the same. However, perhaps, owing to the relatively small number of observations, statistical significance is generally scant. One final procedure, endogenous switching point models, is used to more carefully examine the patterns of elasticity along the river. In practice, equation [8] is run on the entire sample allowing the elasticity to vary between the Mississippi and Illinois rivers.[23] To find any switch points, an additional dummy variable is interacted with barge demand for every possible point of segmentation of the waterway system i.e., every observation. For example, suppose that there are 5 elevators on the river. According to this endogenous switch point model, equation [8] would be run 4 times, once for each possible break point.[24] The break point that yields the highest level of significance is then chosen as the first break point (F-tests are used to evaluate the significance levels). Given this break point, an additional dummy variable is interacted with barge rate in equation [8] allowing

[23] Tests indicate that that the Mississippi and Illinois barge elasticities are, in fact, different at the 99% level.
[24] The possible break points would be at elevator 2 (meaning that elevator 1 and elevators 2-5 have different elasticities), elevator 3, elevator 4, and elevator 5.

the elasticity to vary between the Mississippi River, the Illinois River and the two subsets of data defined by the break point found.[25] The process is then started over to determine if there are additional switch points present in each subset.

When applied to the data, this method finds that there are six break points which provide six different elasticity estimates, on the Upper Mississippi and Illinois Rivers. To control for these break points, dummy variables, interacted with barge rate, are added to equation [8]. The specification of these dummy variables is outlined in Table 4. Table 5 presents the elasticity estimates obtained from this break point methodology. On the Upper Mississippi River, Figure 7, barge demand elasticity is found to varying between -1.448 and -1.987. Similar to the results found from the previous parametric approach of interacting barge rate and river mile, these results indicate that barge demand is more elastic on the southern (-1.815) and northern (-1.987) ends of the river as compared to the center of the Upper Mississippi River (-1.668, -1.702 and -1.448). For the Illinois River, Figure 8, elasticity varying very little between the two sections of the river as indicated by the endogenous switch point method, with elasticity being -1.869 below lock 5 and -1.874 above lock 5.

Spatial Autocorrelation

Again noting the spatial nature of these data, a spatial autocorrelation model is estimated as a robustness check of the results. A spatial autocorrelation, or spatial error, model as described by Anselin (1988) relaxes the OLS assumption of the independence

[25] The specific break point is at the pool level for the break point that yields the largest test statistic.

of error terms to account for unobserved spatial similarities of elevators.[26] In particular, the spatial error model is given by:

$$\begin{aligned} y &= X\beta + \varepsilon \\ \text{where } \varepsilon &= \lambda W\varepsilon + u \end{aligned} \tag{9}$$

where y is the n by 1 vector of elevator annual ton-miles and X is an n by k vector of the explanatory variables present in equation [8]. Notice that this equation is no different than the OLS specification of equation [8]. However, to this equation structure is added to the error term by specifying that errors are correlated across space rather than being independent. Specifically, the error term is augmented by $\lambda W\varepsilon$, where W is a row standardized spatial weight matrix which relates the errors of observations across space. The particular form of this weight matrix for this study is given by:[27]

$$W_{i,j} = \begin{cases} 0 \ \ if \ \ i = j \\ \dfrac{1}{1+d_{i,j}} \ \ if \ \ i \neq j \end{cases} \tag{10}$$

where $d_{i,j}$ is the degree of contiguity between pools i and j. In particular, pools i and j are first degree contiguous, $d_{i,j} = 1$, if pools i and j share a border, pools i and j are second degree contigous, $d_{i,j} = 2$, if pools i and j are separated by one pool, etc. Notice that zero weight is given to all diagonal elements of the weighting matrix to prevent the error term from being a function of itself.

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[26] The alternative spatial model would be the spatial autoregressive, or spatial lag, model. This model is appropriate when the econometrician believes that there is a direct relationship between dependent variables over space. This model was estimated and the results are nearly identical to those presented for the spatial error model; however, test statistics for the appropriateness of this model indicated that there was no such direct relationship between the dependent variables over space, thus the results of this model are not presented, but are available upon request.

[27] However, other specifications of the weight matrix were examined and did not qualitatively change the results presented. Row standardization is done such that the sum of each row of the spatial weight matrix sums to one, which places the least structure on the spatial specification of the error terms.

Due to the non-spherical error term of the spatial error model, OLS techniques are unbiased, but are inefficient. Therefore, maximum likelihood (ML) techniques are used as is common in the spatial econometric literature. The log-likelihood function of the spatial error model is given by:

$$L = -\frac{n}{2}\ln(2\pi) - \frac{n}{2}\ln\sigma^2 + \ln\left|I - \lambda W\right| - \frac{1}{2\sigma^2}\left[(y - X\beta)'(I - \lambda W)'(I - \lambda W)(y - X\beta)\right] \quad (11)$$

where $\left|I - \lambda W\right|$ is the determinant of the Jacobian expressing the spatial transformation of the disturbance term.[28] The existence of this Jacobian term in equation [11] complicates the numerical optimization of the likelihood function as this requires calculating the determinant of an *n* by *n* matrix. However, Ord (1975) shows that this Jacobian can be expressed as a function of the eigenvalues, ω_i, of the spatial weighting matrix according to:

$$\left|I - \lambda W\right| = \prod_{i=1}^{N}(1 - \lambda\omega_i) \quad (12)$$

The advantage of this calculation being that it only has to be done once.

This model is estimated both with constant elasticity and with geographically varying elasticity with break points from the endogenous switching point model. The non-elasticity results of this specification are presented in Table 6, while the elasticity estimates are presented separately in Table 7. The results of each of these models do not suggest any improvement in precision by modeling the spatial autocorrelation. This result adds credence to the observable spatial control variables included in equation [8], in that they capture the local competitive environment of grain elevators well enough that

[28] The log likelihood function given by [11] differs from the log likelihood function of a non-spatial linear regression model through this Jacobian term.

the spatial autocorrelation model, which is designed to capture unobserved spatial characteristics, is found to be unwarranted.

Additionally, the results of the spatial autocorrelation model are qualitatively equivalent to those previously found via OLS and fixed effects. The elasticity estimates from the spatial autocorrelation specification are shown in Table 7, Figure 9 for the Upper Mississippi River, and Figure 10 for the Illinois River. Under the assumption of constant elasticity, the barge demand elasticity is estimated to be -1.607. Using the endogenous switch point elasticity method, barge demand is estimated to be between -1.350 and -1.562 for the Upper Mississippi River and -1.558 and -1.592 for the Illinois River. Examining the patterns of elasticity in Figures 9 and 10, the same patter of barge demand is found, where demand is estimated to be more elastic on the southern (-1.542) and northern (-1.562) ends of the Upper Mississippi River and more inelastic towards the center (-1.350, -1.374 and -1.556). For the Illinois River, barge demand is slightly more elastic above lock 5, -1.592, as compared to below lock 5, -1.558.

6. Conclusion

The aim of this study was to develop a theoretical model of spatial demand and the subsequent barge transportation demand of grain elevators, and to obtain estimates of the elasticity of barge demand. These estimated demand elasticities are of particular importance due to the current controversy over the assumptions on the magnitude of barge demand elasticity made in current policy planning models. This study finds elasticity estimates between -1.350 and -1.987, estimates which leads to the conclusion that the assumption of perfectly inelastic transportation demand made by the planning models is inappropriate and may lead to erroneous benefit estimation.

This study also examined the existence of non-constant geographically varying elasticity. To obtain the appropriate geographic pattern of barge demand elasticity along the waterway system, both rolling regressions and locally weighted regressions models were used to first visually examine the data. Two parametric approaches were then used to obtain estimates of barge demand elasticity along the Upper Mississippi and Illinois Rivers. The first of these parametric approaches showed that the barge demand elasticity does not vary systematically along the waterway system. The second parametric approach allowed break points to be endogenously determined, and found 4 break points on the Upper Mississippi River and 2 break points on the Illinois River. Using these endogenous break points, barge demand was found to be more elastic on the northern and southern ends of the Upper Mississippi River as compared to the center of the river.

Finally, a model of spatial autocorrelation was used as a robustness check of the results. The results of this model indicate that errors are not spatially correlated, and provide evidence that the observed spatial competition variables capture the local competitive atmosphere.

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List of Tables and Figures:

FIGURE 1: Barge Terminal Locations of Grain Shippers

Locations of the grain elevators located along the Upper Mississippi (North of Cairo, IL.) and Illinois Rivers.

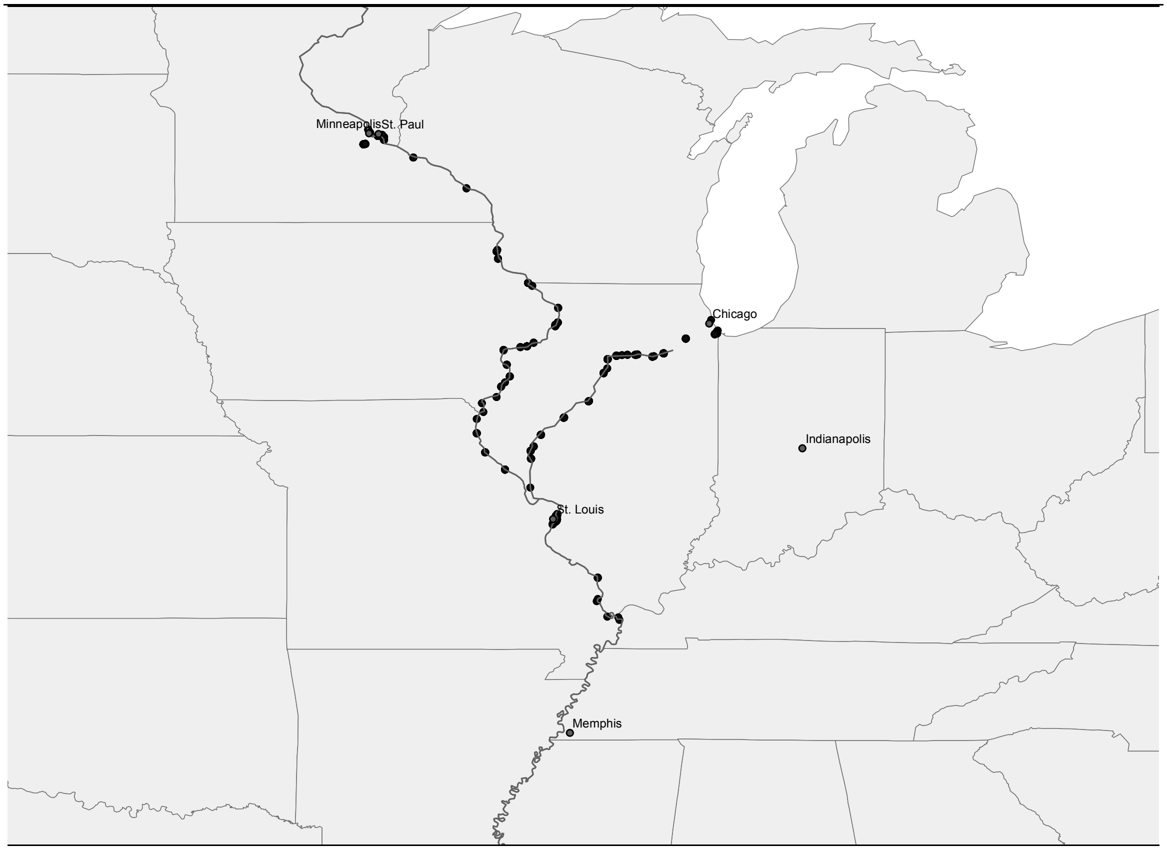


FIGURE 2: Median Gathering Areas

The firm's gathering defined as the distance that they report procuring crops from. The elevators are then grouped by river segment and the median gathering area of these groups is calculated.

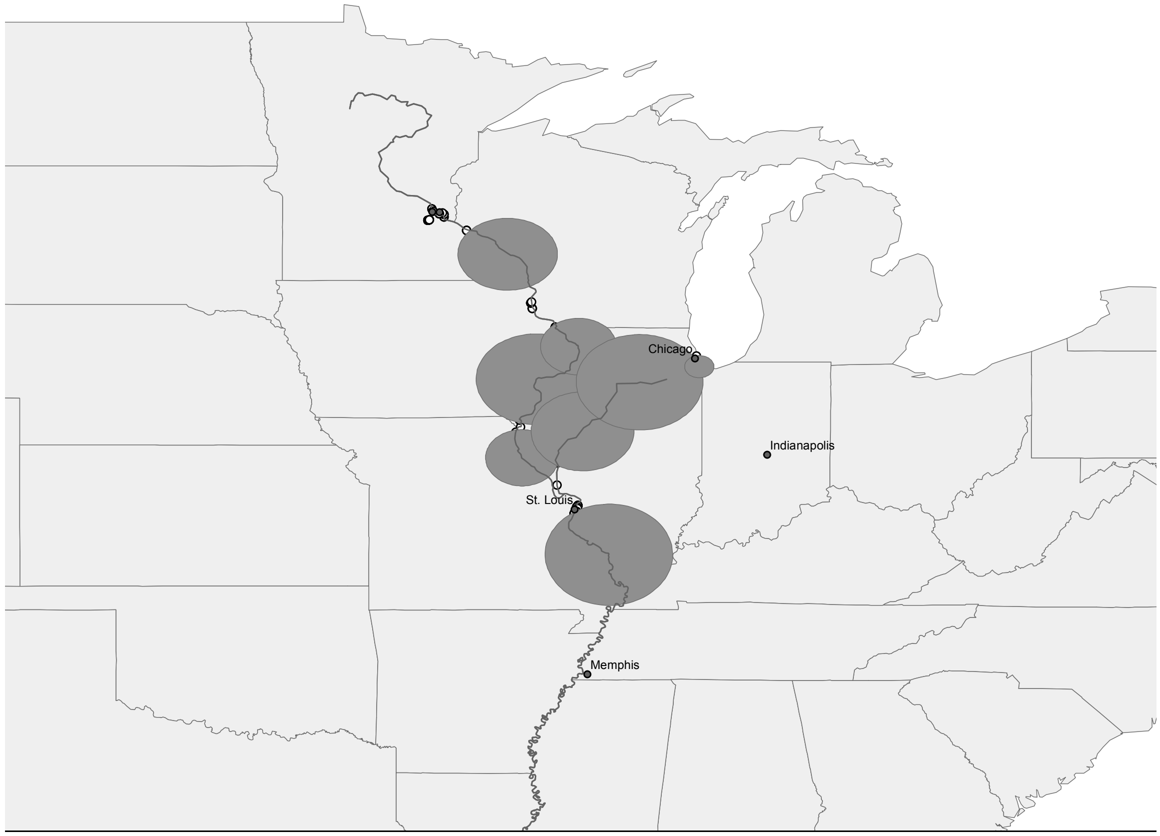


TABLE 1: Descriptive Statistics

The sample of 103 observations of grain elevators on the Upper Mississippi and Illinois Rivers collected via survey by the Tennessee Valley Authority (TVA). Annual ton-miles is measured as the annual tons shipped by a grain elevator multiplied by the distance of the shipments. Barge rate is the barge charge per ton divided by the miles of the movement. Transportation Rate to Elevator is the rate per ton (via truck or rail) to the barge loading facility divided by the miles transported to the elevator. Alternative Rate is the rail, truck and/or barge rate per ton-mile of the next best alternative to shipping down the river. Firm Capacity is the capacity, in bushels, of the firm. Distance to Nearest Competitor is the distance, in miles, to the nearest competitor either upstream or downstream. Area Capacity is the capacity of the firms in the same pool minus the firm's own capacity. Number of firms in the Area is the number of competing elevators in the same pool. Area Production is taken from the USDA's county level crop output database, and is defined as the average production of the commodity being shipped in the elevator's county and bordering counties. % of Shipments that are Corn is the number of annual corn shipments divided by the total number of shipments. Gathering Area is the distance the commodity traveled to arrive at the river port barge loading facility.

Variable	Centile	Average
Annual Ton-Miles (thousand)	15,400	47,800
Barge Rate	0.012	0.011
Transportation Rate to Elevator	0.091	0.099
Alternative Rate	0.129	0.131
Firm Capacity (thousand)	550	1,505
Distance to Nearest Competitor	2.5	7.69
Area Capacity (thousand)	2,020	4,119
Number of Area Firms	5	4.6
Area Production (thousand)	47,500	61,100
% of Shipments that are Corn	0.5	0.454
Gathering Area	60	71.1

TABLE 2: Results of Annual Ton-Mile Regressions Using OLS and FE Models

The dependent variable, Log(Annual Ton-Miles) is measured as the annual tons shipped by a grain elevator multiplied by the distance of the shipments.

	OLS without Regional Characteristics	OLS with Regional Characteristics	Pool Fixed Effects without Regional Characteristics	Pool Fixed Effects with Regional Characteristics
Log (Barge Rate)	-1.414**	-1.614***	-1.508**	-1.799***
	(0.583)	(0.597)	(0.635)	(0.648)
Log (Transportation Rate to Elevator)	-1.241**	-1.236**	-1.520**	-1.674***
	(0.550)	(0.565)	(0.633)	(0.628)
Log (Alternative Rate)	-0.365	-0.192	-0.486	-0.082
	(0.746)	(0.749)	(0.866)	(0.874)
Log (Capacity)	0.166	0.205*	0.288	0.330
	(0.114)	(0.118)	(0.210)	(0.366)
Conglomerate Firm Dummy Variable	0.969***	0.863**	0.514	0.427
	(0.330)	(0.337)	(0.438)	(0.453)
% of Shipments that are Corn	1.859***	1.396***	1.749***	1.400***
	(0.409)	(0.461)	(0.449)	(0.504)
Log (Pool Capacity)		-0.058		0.193
		(0.045)		(0.656)
Log (Area Production)		0.128**		0.124*
		(0.062)		(0.066)
Distance to Nearest Competitor		-0.023		-0.036
		(0.017)		(0.029)
Number of Firms in Same Pool		0.066		
		(0.081)		
Constant	2.576	0.261	-0.029	-5.555
	(2.943)	(3.349)	(4.187)	(13.078)
Observations	103	103	103	103
Pools			23	23
R^2	.36	.40	.50	.53

Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

FIGURE 3: Rolling Regressions Estimates with Window Size 40

Elasticity estimates using a rolling regressions estimation technique (see text for details) of the model presented in Table 2 with a window size of 40. Other window sizes were used and the results are available from the author upon request.

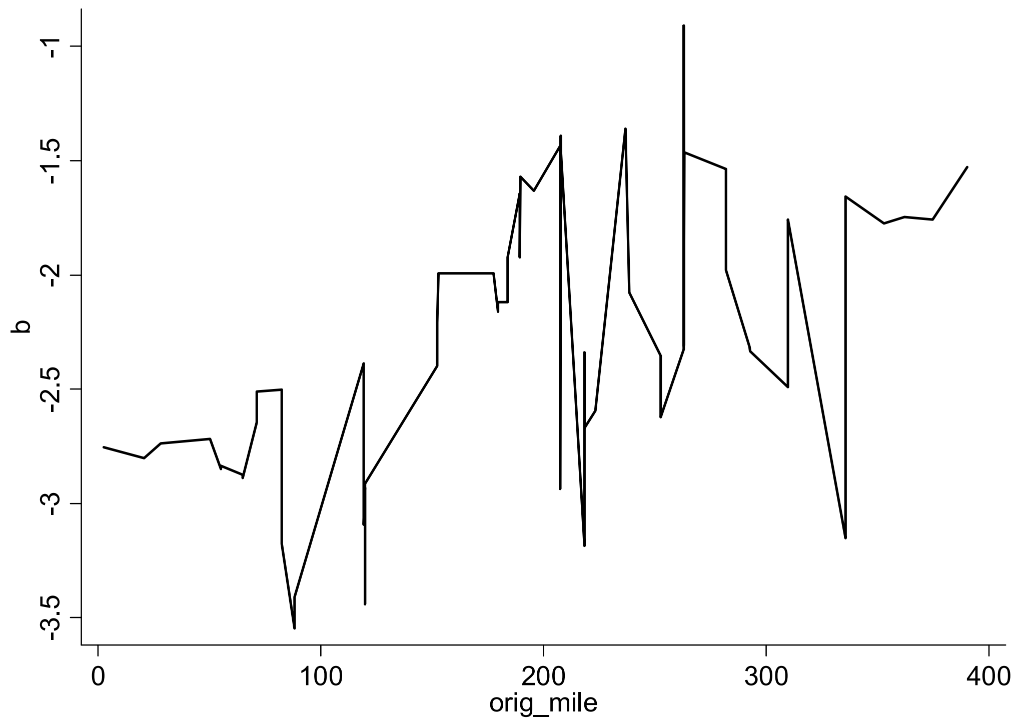


FIGURE 4: Locally Weighted Regressions Estimates with Window Size 40

Elasticity estimates using a locally weighted regression estimation technique (see text for details) of the model presented in Table 2 with a window size of 40. Other window sizes were used and the results are available from the author upon request.

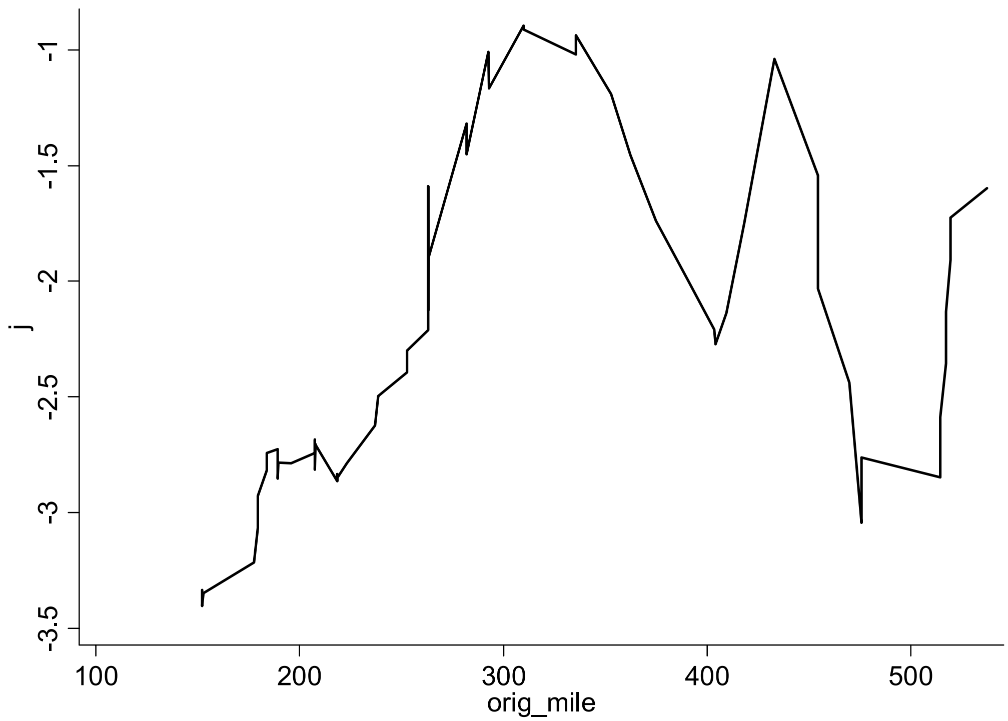


TABLE 3: Parametric Geographically Varying Elasticity Estimates

Using interaction terms of river mile with elasticity, geographically varying elasticity estimates of the same model presented in Table 2 for each river system.

Model	Barge Rate Estimate	Barge Rate Interacted with River Mile Estimate	Barge Rate Interacted with River Mile Squared Estimate	Barge Rate Interacted with River Mile Cubed Estimate
Upper Mississippi River				
Constant Elasticity	-1.574** (0.603)			
Linear Elasticity in River Mile	-1.390** (0.626)	-0.0002 (0.0002)		
Quadratic Elasticity in River Mile	-1.611** (0.660)	0.0007 (0.0009)	-0.000002 (0.000002)	
Cubic Elasticity in River Mile	-1.681** (0.661)	-0.003 (0.002)	0.00002 (0.00001)	-0.00000002 (0.00000001)
Illinois River				
Constant Elasticity	-1.632*** (0.600)			
Linear Elasticity in River Mile	-1.593** (0.618)	0.0003 (0.0007)		
Quadratic Elasticity in River Mile	-2.059*** (0.669)	0.007* (0.004)	-0.00004 (0.00003)	
Cubic Elasticity in River Mile	-1.854*** (0.696)	-.008 (0.011)	0.0002 (0.0001)	-0.0000006 (0.0000004)

Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

FIGURE 5: Parametric Varying Elasticity Estimates for the Upper Mississippi River

Using interaction terms of river mile with elasticity, geographically varying elasticity estimates of the same model presented in Table 2 for the Upper Mississippi River system.

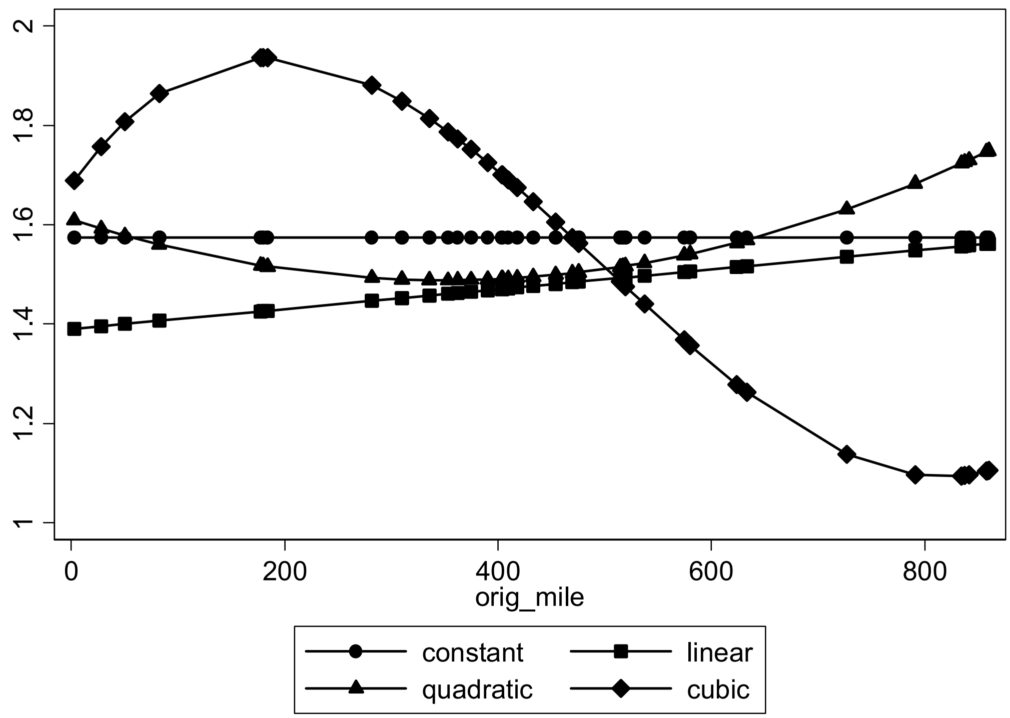


FIGURE 6: Parametric Varying Elasticity Estimates for the Illinois River

Using interaction terms of river mile with elasticity, geographically varying elasticity estimates of the same model presented in Table 2 for the Illinois River system.

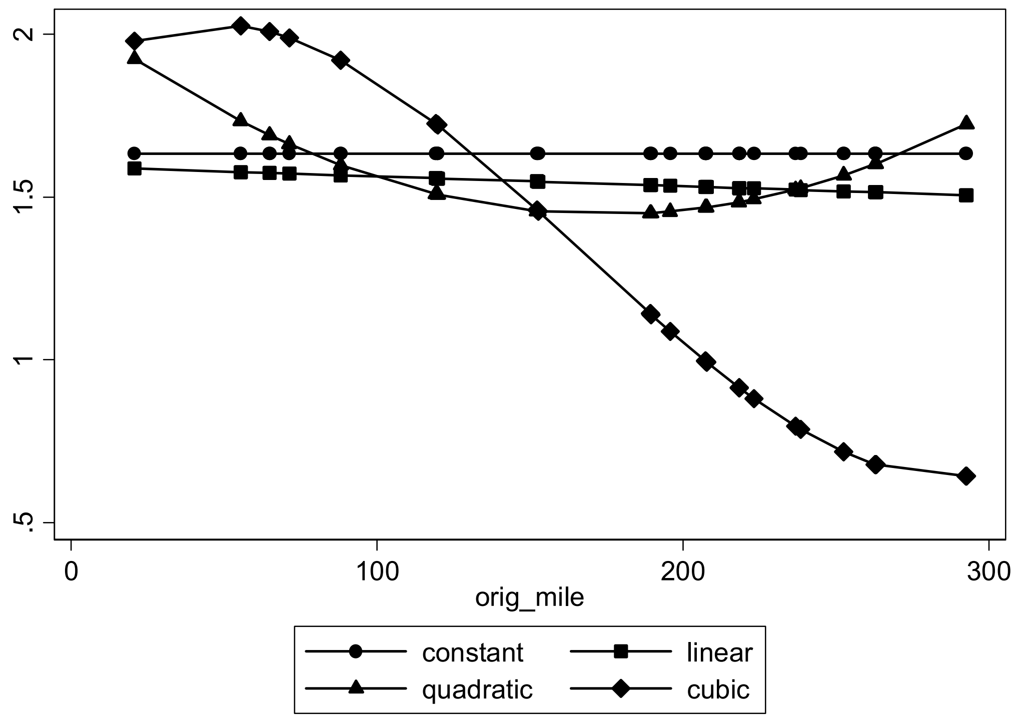


TABLE 4: Definition of Elasticity Dummy Variables along the Waterway System

Using an endogenous switch point methodology (see text for details), there were six regions of elasticity found along the waterway system.

Grouping	River Segment
1	Illinois River Below Marseilles Lock (Mile 244.6)
2	Illinois River Above Marseilles Lock (Mile 244.6)
3	Upper Mississippi River Below Lock 27 (Mile 185.5)
4	Upper Mississippi River Between Locks 27 (Mile 185.5) & 16 (Mile 457.2)
5	Upper Mississippi River Between Locks 16 (Mile 457.2) & 10 (Mile 615.1)
6	Upper Mississippi River Between Locks 10 (Mile 615.1) & 2 (Mile 815.2)
7	Upper Mississippi River Above Lock 2 (Mile 815.2)

TABLE 5: Endogenous Switch Point Elasticity Estimates from OLS

Using the elasticity regions defined in Table 4, geographically varying elasticity estimates of the same model presented in Table 2 for each river system.

Upper Mississippi River

	Below Lock 27	Between Locks 27 & 16	Between Locks 16 & 10	Between Locks 10 & 2	Above Lock 2
Elasticity	-1.815***	-1.668***	-1.702***	-1.448**	-1.987***
	(0.640)	(0.611)	(0.604)	(0.608)	(0.617)

Illinois River

	Illinois River Below Lock 5	Illinois River Above Lock 5
Elasticity	-1.869***	-1.874***
	(0.611)	(0.618)

Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

FIGURE 7: Regional Elasticity Estimates for the Upper Mississippi River from OLS

Using the elasticity regions defined in Table 4, geographically varying elasticity estimates of the same model presented in Table 2 for the Upper Mississippi River system.

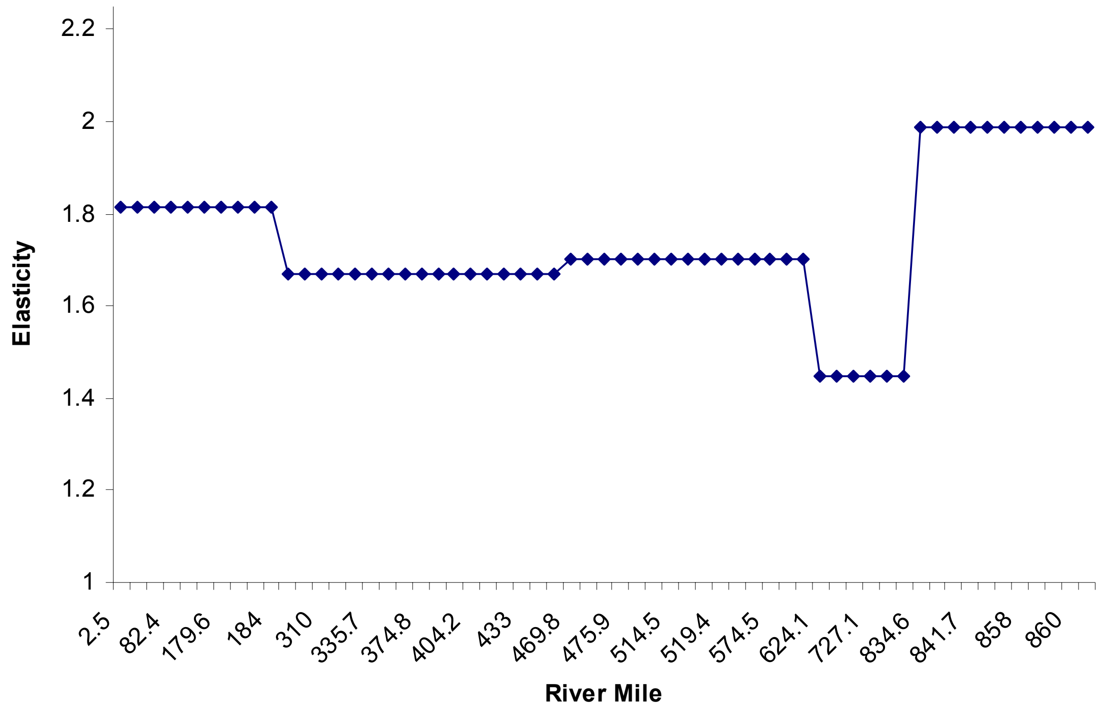


FIGURE 8: Regional Elasticity Estimates for the Illinois River

Using the elasticity regions defined in Table 4, geographically varying elasticity estimates of the same model presented in Table 2 for the Illinois River system.

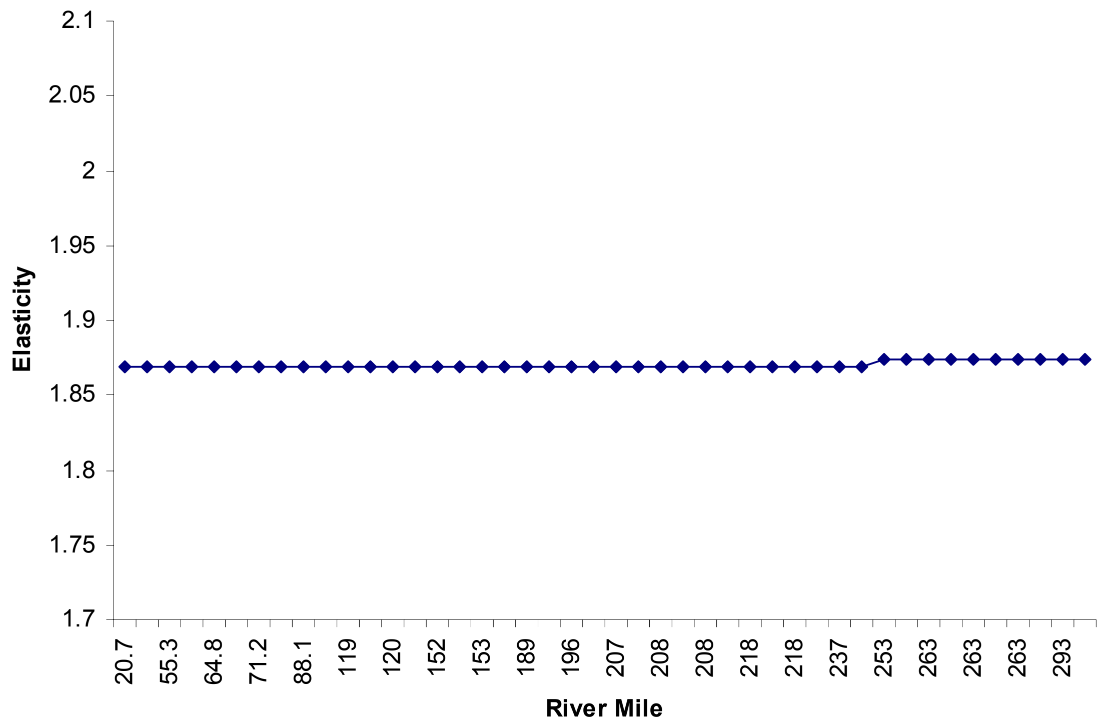


TABLE 6: Non-Elasticity Results from the Spatial Autocorrelation Model

The dependent variable, Log(Annual Ton-Miles) is measured as the annual tons shipped by a grain elevator multiplied by the distance of the shipments. The geographic elasticity model is estimated using the elasticity regions defined by Table 4. The weighting matrix used for the spatial autocorrelation model is defined as (see text for details):

$$W_{i,j} = \begin{cases} 0 \text{ if } i = j \\ \frac{1}{1+d_{i,j}} \text{ if } i \neq j \end{cases}$$

where $d_{i,j}$ is the degree of contiguity between pools i and j, i.e. pools i and j are first degree contiguous, and $d_{i,j}$ =1 if they share a border, second degree contiguous, $d_{i,j}$ = 2 if they are separated by 1 pool, etc.

	Constant Elasticity	Geographically Varying Elasticity
Log (Transportation Rate to Elevator)	-1.177** (0.555)	-1.048* (0.588)
Log (Alternative Rate)	-0.242 (0.721)	-0.365 (0.747)
Log (Capacity)	0.209* (0.111)	0.279** (0.135)
Log (Pool Capacity)	-0.056 (0.042)	-0.077* (0.046)
Number of Firms in Same Pool	0.070 (0.075)	0.021 (0.096)
Log (Area Production)	0.129** (0.059)	0.143** (0.061)
Distance to Nearest Competitor	-0.022 (0.016)	-0.025 (0.017)
% of Shipments that are Corn	1.385*** (0.436)	1.131** (0.457)
Conglomerate Firm Dummy Variable	0.847*** (0.322)	0.714** (0.327)
Constant	0.208 (3.133)	0.235 (3.208)
Lambda	-0.106 (0.315)	-0.468 (0.435)
Observations	103	103
Log-Likelihood	-180.224	-177.972

Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

TABLE 7: Estimated Elasticity Estimates from the Spatial Autocorrelation Models

The dependent variable, Log(Annual Ton-Miles) is measured as the annual tons shipped by a grain elevator multiplied by the distance of the shipments. The geographic elasticity model is estimated using the elasticity regions defined by Table 4. The weighting matrix used for the spatial autocorrelation model is defined as (see text for details):

$$W_{i,j} = \begin{cases} 0 \text{ if } i = j \\ \frac{1}{1+d_{i,j}} \text{ if } i \neq j \end{cases}$$

where $d_{i,j}$ is the degree of contiguity between pools i and j, i.e. pools i and j are first degree contiguous, and $d_{i,j}$ =1 if they share a border, second degree contiguous, $d_{i,j}$ = 2 if they are separated by 1 pool, etc.

From the Constant Elasticity Specification

Elasticity	-1.607*** (0.551)

From the Geographically Varying Elasticity Specification

For the Upper Mississippi River

	Below Lock 27	Between Locks 27 & 16	Between Locks 16 & 10	Between Locks 10 & 2	Above Lock 2
Elasticity	-1.542*** (0.520)	-1.350** (0.554)	-1.374*** (0.517)	-1.556*** (0.520)	-1.562*** (0.536)

For the Illinois River

	Illinois River Below Lock 5	Illinois River Above Lock 5
Elasticity	-1.558*** (0.511)	-1.592*** (0.523)

Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

FIGURE 9: Endogenous Elasticity Estimates for the Upper Mississippi River from the Spatial Autoregressive Model

Using the elasticity regions defined in Table 4, geographically varying elasticity estimates of the same model presented in Table 2 for the Upper Mississippi River system with spatially autocorrelated errors.

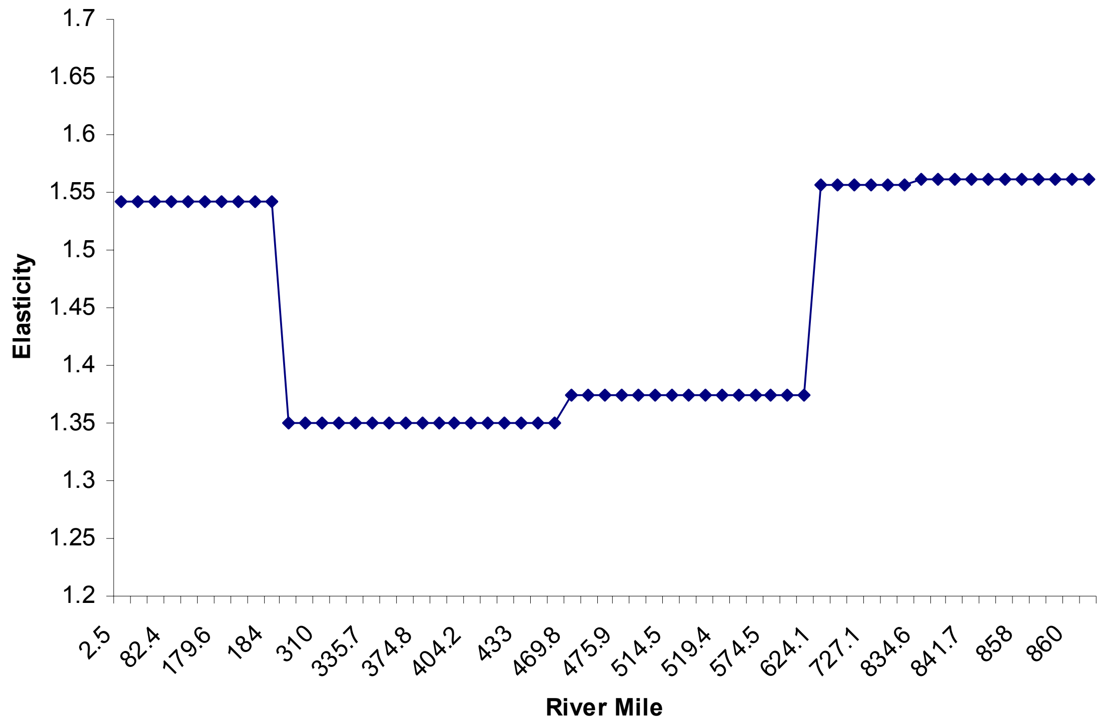
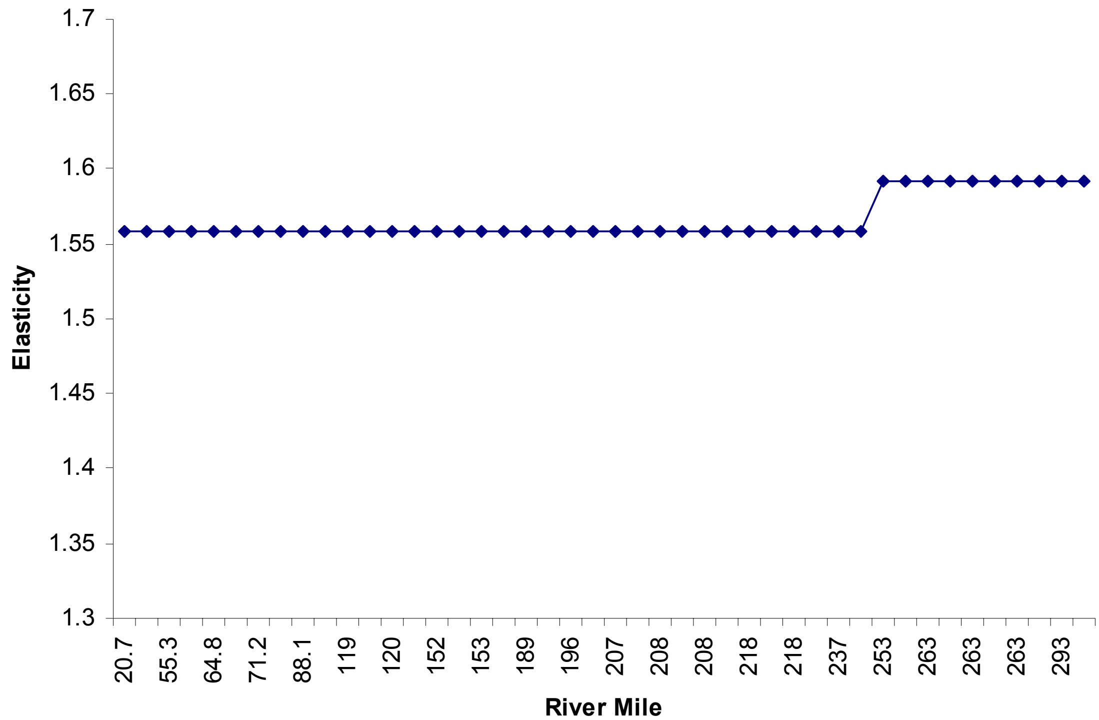


FIGURE 10: Endogenous Elasticity Estimates for the Illinois River from the Spatial Autoregressive Model

Using the elasticity regions defined in Table 4, geographically varying elasticity estimates of the same model presented in Table 2 for the Illinois River system with spatially autocorrelated errors.



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The NETS research program is developing a series of practical tools and techniques that can be used by Corps navigation planners across the country to develop consistent, accurate, useful and comparable information regarding the likely impact of proposed changes to navigation infrastructure or systems.

The centerpiece of these efforts will be a suite of simulation models. This suite will include:

- A model for forecasting international and domestic traffic flows and how they may be affected by project improvements.
- A regional traffic routing model that will identify the annual quantities of commodities coming from various origin points and the routes used to satisfy forecasted demand at each destination.
- A microscopic event model that will generate routes for individual shipments from commodity origin to destination in order to evaluate non-structural and reliability measures.

As these models and other tools are finalized they will be available on the NETS web site:

http://www.corpsnets.us/toolbox.cfm

The NETS bookshelf contains the NETS body of knowledge in the form of final reports, models, and policy guidance. Documents are posted as they become available and can be accessed here:

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