A Model of Spatial Market Areas and Transportation Demand

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Background

- There are three models currently used for welfare analysis purposes:
  - The Tow-Cost Model (TCM)
  - The Ohio River Navigation Investment Model (ORNIM)
  - The ESSENCE Model
- Each of these models define demand in terms of O-D-C triples
  - Each of these models further makes an assumption about the behavior of demand in response to rate movements:

Contribution to the Literature

- There is little empirical work looking at the interactions of firms in space
- There is little transportation demand work incorporating space
- I theoretically and empirically analyze the interactions of agricultural elevators incorporating the spatial attributes of the elevators

My Approach

- The O-D-C triples reflect the decisions of port elevators
- This study examines the responsiveness of these elevators to barge rates using:
  - A model of transportation demand
  - And the interrelated supply decisions of port elevators
- The model takes into account geographic space
- Using this model, elasticity is found to be reasonably elastic

Background

- The Market Setting:
  - Focusing on agricultural commodities
  - At harvest, the farmers must decide where to sell their crops
  - These crops almost always go from the farmer to a gathering point where they are then sent to their final destination
  - These gathering points compete against each other in the procurement of these crops

Theoretical Model

- Assume that:
  - There are $n=1,2,\ldots,N$ elevators
  - Elevators are located $D=d_{12},d_{23},\ldots,d_{n-1n}$ miles apart
  - Grain is evenly distributed between the elevators with parameter y.
  - Farmers choose where to send their grain according to:

$$(w^e + \delta_e - \theta D^e)$$

  - According to this equation, each elevator's market area is defined by the location of the indifferent customer:

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

Theoretical Model

- Using this knowledge, total output for elevator A is:

$$Q^{A} = Dy\left\{\int_{0}^{D^{A-B}} \frac{1}{D} dt_1 + \int_{0}^{D^{A-C}} \frac{1}{D} dt_2\right\} = Dy\left\{\frac{D^{A-B}}{D} + \frac{D^{A-C}}{D}\right\}$$

$$= \frac{y}{2\theta}\left\{2w^{A} - w^{B} - w^{C} + 2\delta_{\mathrm{A}} - \delta_{\mathrm{B}} - \delta_{C}\right\} + \frac{Dy}{2}$$

Theoretical Model

- This equation can be rearranged to:

$$w^{A} = \frac{1}{2}\left\{w^{B} + \delta_{B} + w^{C} + \delta_{C}\right\} + \frac{\theta}{y}\left\{Q^{A} - \frac{D\,y}{2}\right\} - \delta_{A}$$

- The elevator’s procurement costs are then:

$$\mathrm{C}^{\mathrm{Procurement}} = w^{\mathrm{A}}Q^{\mathrm{A}} = \mathrm{C}^{\mathrm{Procurement}}(Q^{\mathrm{A}}, w^{\mathrm{B}}, w^{\mathrm{C}}, D, y, \delta_{\mathrm{A}}, \delta_{\mathrm{B}}, \delta_{\mathrm{C}})$$

- The elevator’s total cost is then:

$$C^{Elevator} = C^{Operations}(Q^{A}, w, K) + C^{\mathrm{Pr}ocurement}(Q^{A}, w^{B}, w^{C}, D, y, \delta_{A}, \delta_{B}, \delta_{C})$$

$$= C(Q^{A}, w, K, w^{B}, w^{C}, D, y, \delta_{A}, \delta_{B}, \delta_{C})$$

Theoretical Model

- The elevator's problem then becomes:

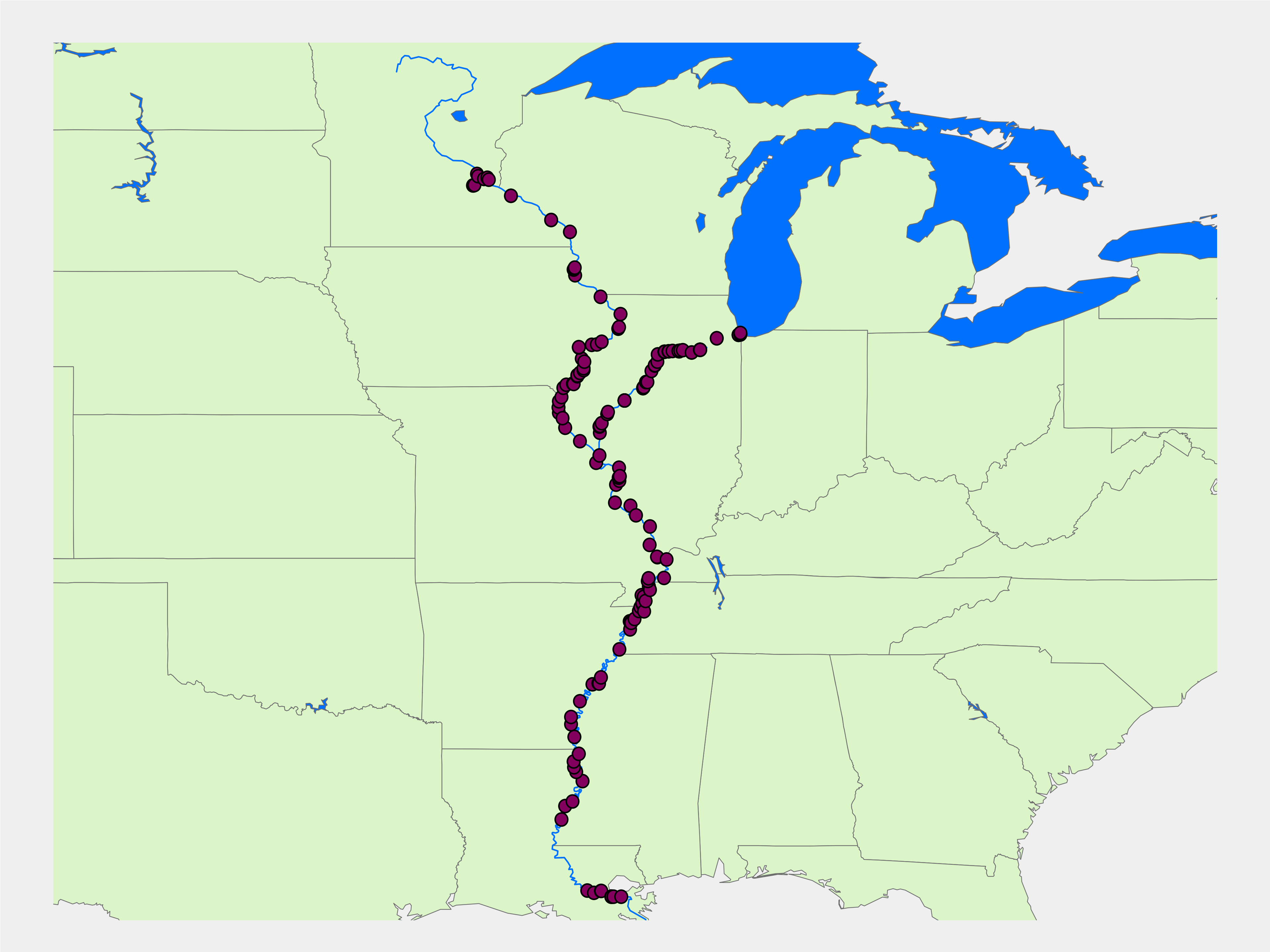
$$Max\,\pi = (P - t)Q - C(Q)$$

- Which when solved yields:

$$Q^* = Q^*(P, t, c)$$

Data

- There are approximately 200 elevators located along the Mississippi & Illinois Rivers who ship grain:



Data

- For this study, I employ a subset of the data
  - The majority of data used for this analysis came from the Tennessee Valley Authority (TVA)
  - In particular, I limit myself to the activities of the 103 grain elevators located on the Upper Mississippi and Illinois rivers:


MinneapolisSt. Paul
Chicago
Indianapolis
St. Louis
Memphis

Empirical Model

- The empirical estimation equation has two ‘types’ of variables
  - Theoretical Variables: Barge Rate, Transportation Rate, Distance to Nearest Competitor, Area Production, A Dummy Variable for Conglomerate Firms, and Firm Capacity
  - Spatial Control Variables: The Number of Firms in the Same Pool, The Capacity of the Firms in the Same Pool, The % of Shipments Which are Corn, and The Alternative Rate

Descriptive Statistics

Variable	Median	Average
Annual Ton-Miles (thousands)	15,400	47,800
Barge Rate	.012	.011
Transportation Rate to Elevator	0.091	.099
Alternative Rate	.129	.131
Firm Capacity (thousands)	550	1,505
Distance to Nearest Competitor	2.5	7.69
Area Capacity (thousands)	2,020	4,119
Number of Firms in Area	5	4.6
Gathering Area	60	71.1

Empirical Model

- The model is estimated using both OLS and area specific fixed effects
  - Firms were defined as being in the same area if they were in the same "pool"

Results

- The results are presented by:
  - Rates
  - Spatial measures
  - And firm measures

Results - Rates

Annual Output Regression Estimates		
	OLS (R^2: .40)	Fixed-Effects By Area (R^2: .53)
Log (Barge Rate)	-1.614***	-1.80***
Log (Transportation Rate to Elevator)	-1.24**	-1.67***
Log (Alternative Rate)	-0.19	-0.08

Results – Spatial Measures

Annual Output Regression Estimates		
	OLS (R^2: .40)	Fixed-Effects By Area (R^2: .53)
Log (Dist. To Nearest Comp.)	-0.02	-0.04
Log (Pool Capacity)	-0.06	0.19
Number of Firms in Pool	0.07	
% of Corn	1.40***	1.40***

Results – Firm Measures

Annual Output Regression Estimates		
	OLS (R^2: .40)	Fixed-Effects By Area (R^2: .53)
Log (Capacity)	0.21*	0.33
Conglomerate Dummy	0.86**	0.43
Log (Area Production)	0.13**	0.12*

Non-Constant Elasticity

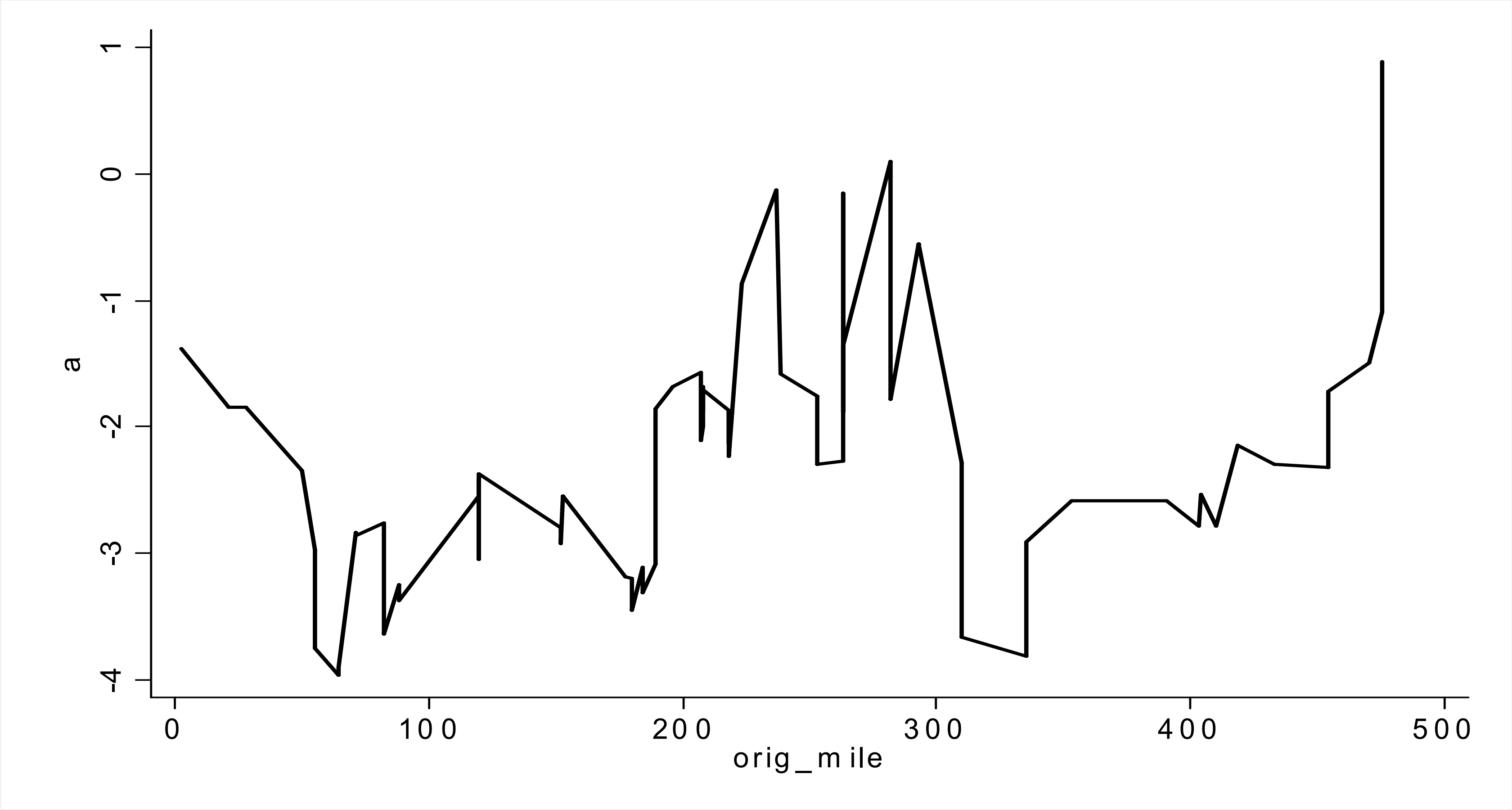
- Possible reasons why elasticity might not be constant along the river
- Approaches to examining the relation between elasticity and the river:
  - Rolling Regressions
  - Locally Weighted Regressions
  - Varying Coefficients
  - Endogenous Switch Points

Rolling Regressions

- Same model run on a “window” of observations
- Elasticity is recorded and the window is rolled forward 1 position

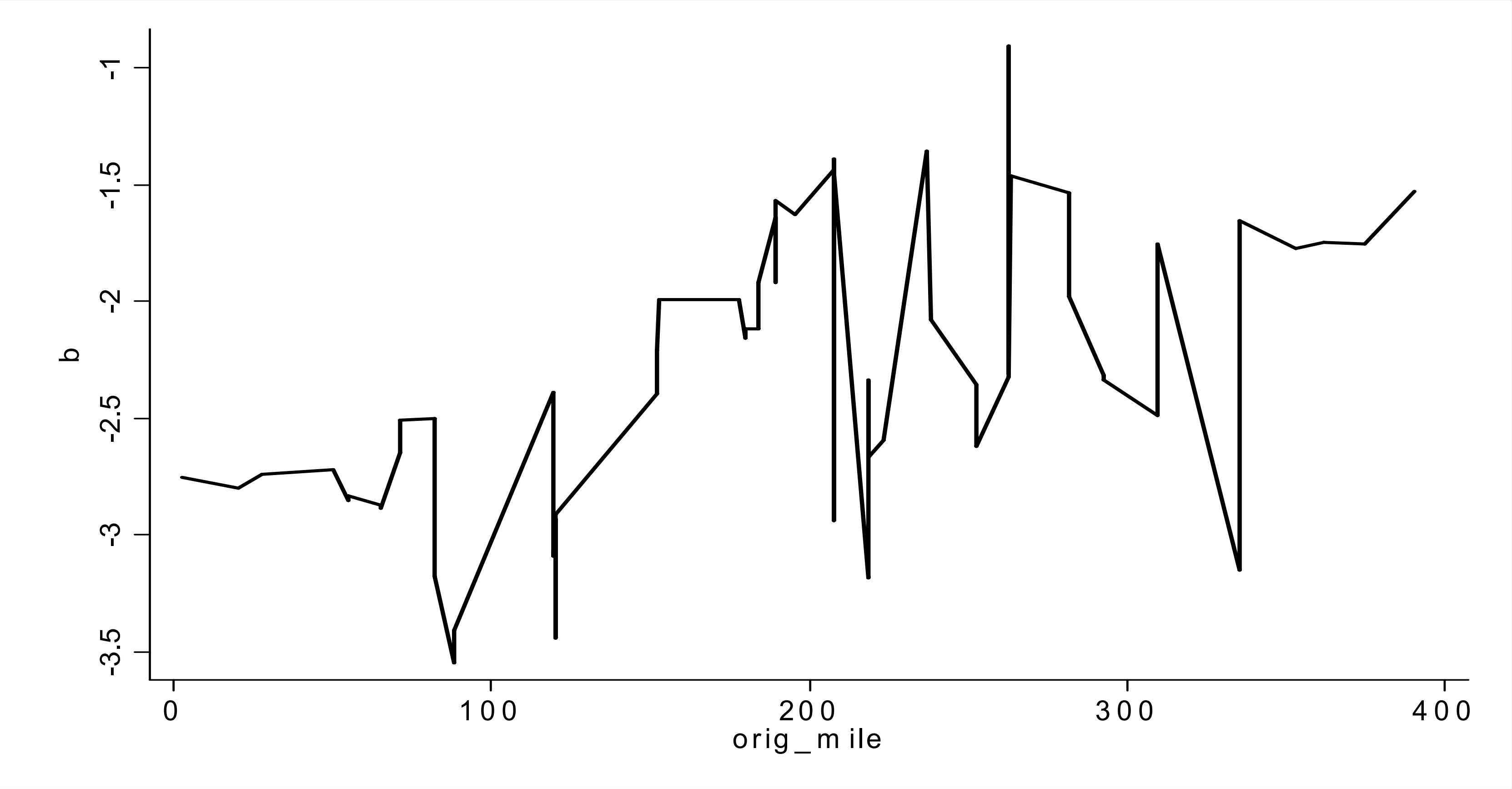
Rolling Regression

- With a window size of 30:



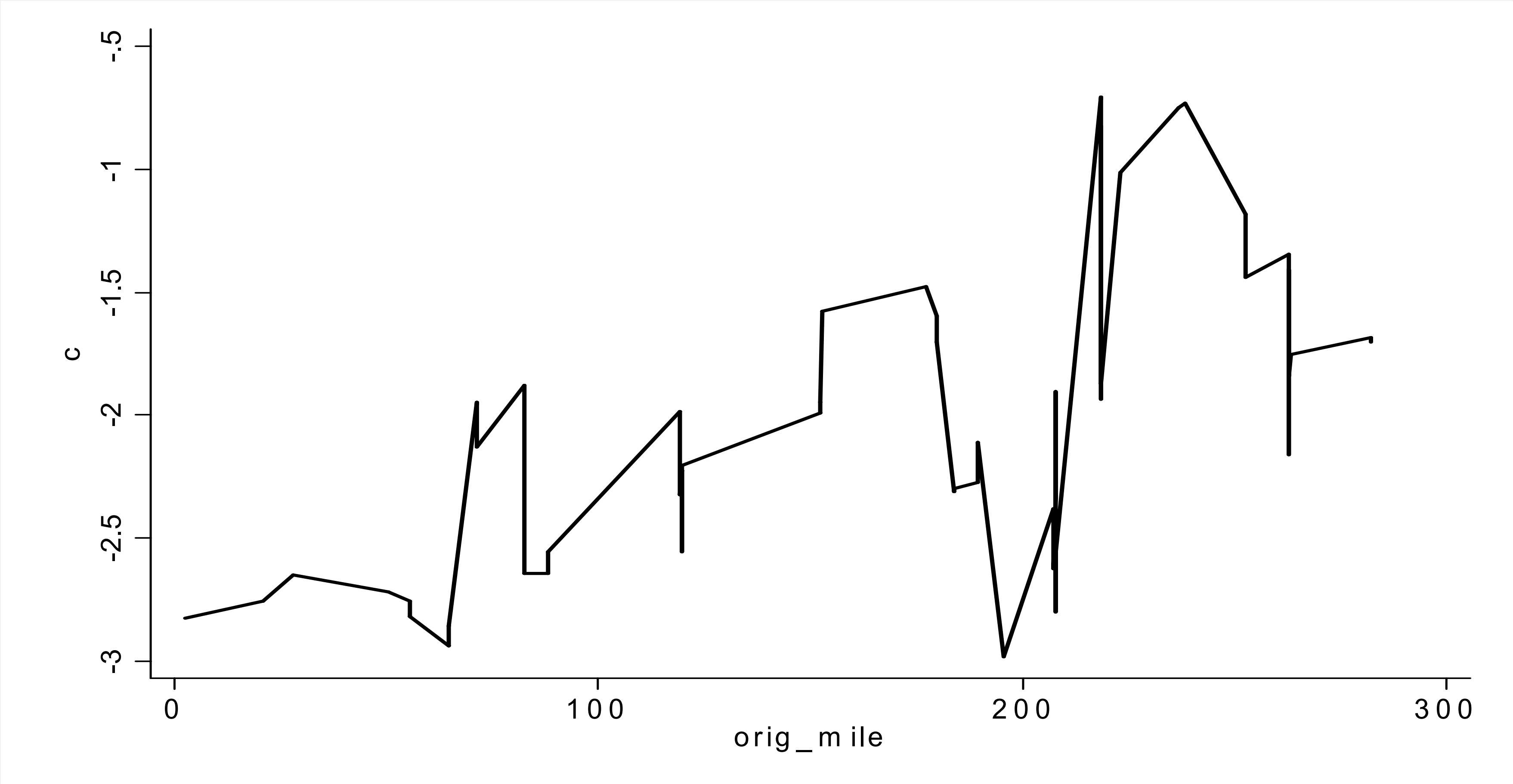
Rolling Regression

- Window size 40:



Rolling Regression

- Window size 50:

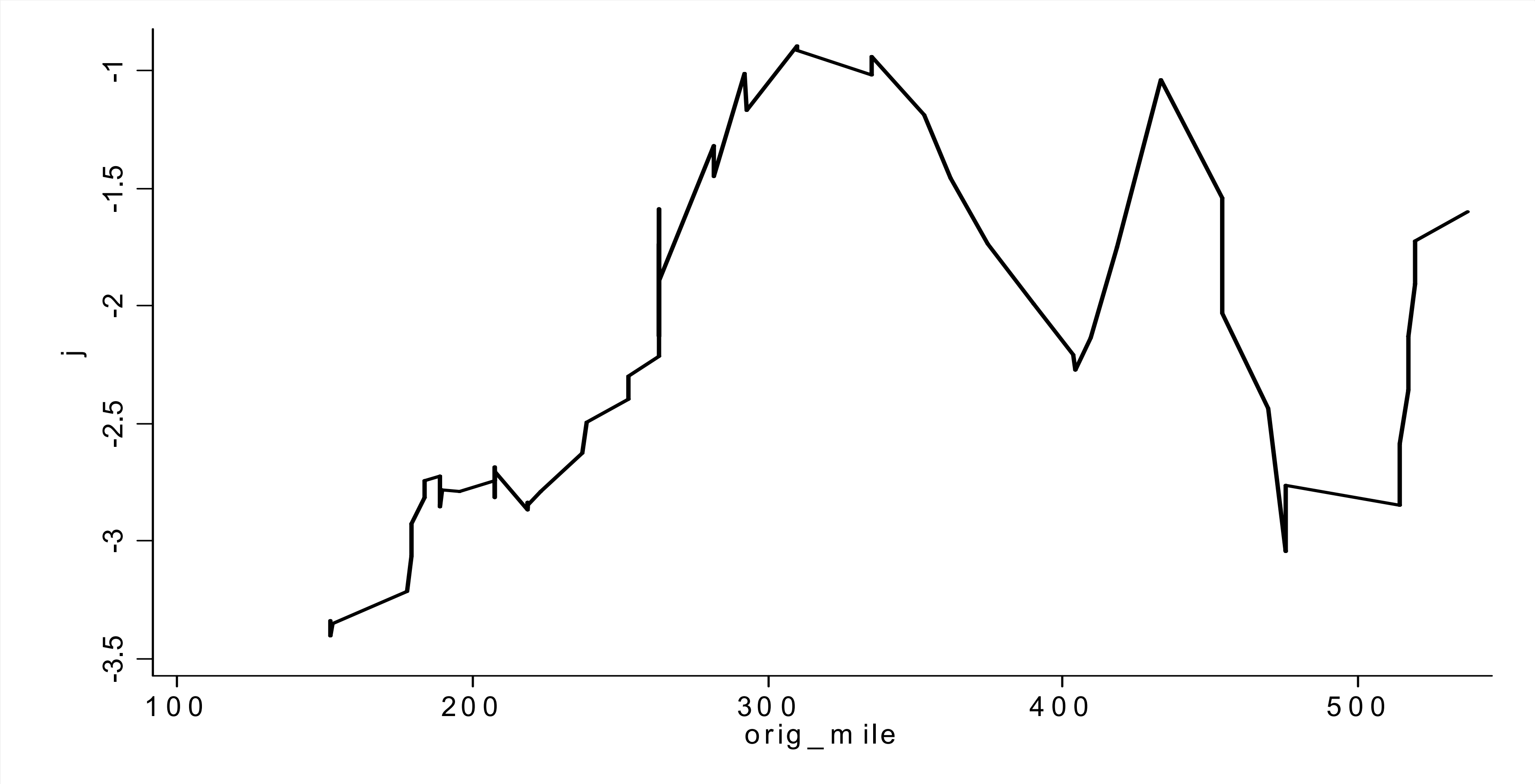


Locally Weighted Least Squares

- Again same model run on a window of observations
- This time with weights attached to each observation
  - Using the tricube specification proposed by Cleveland (1979)

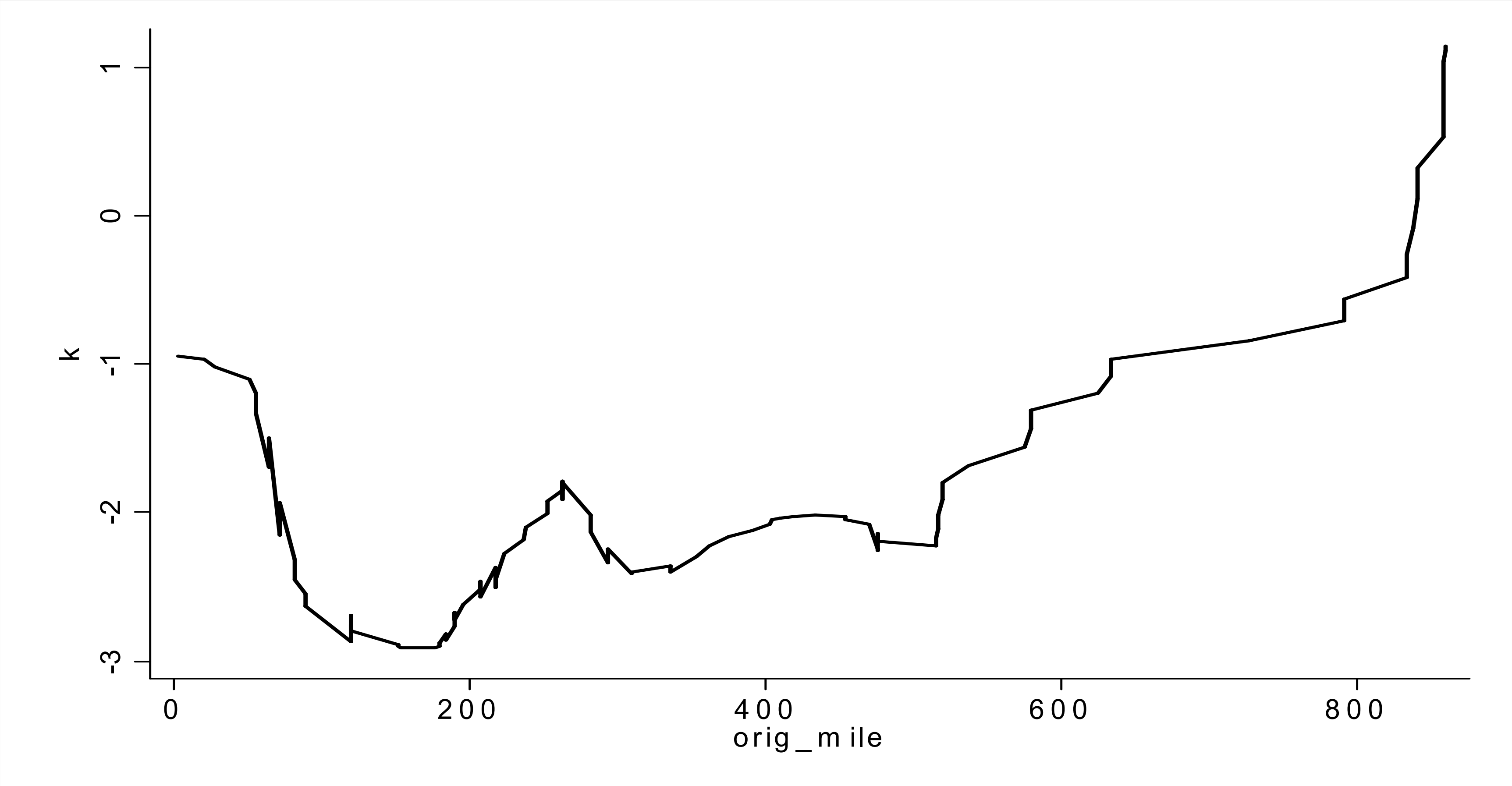
Locally Weighted Regression

- Window size 40:



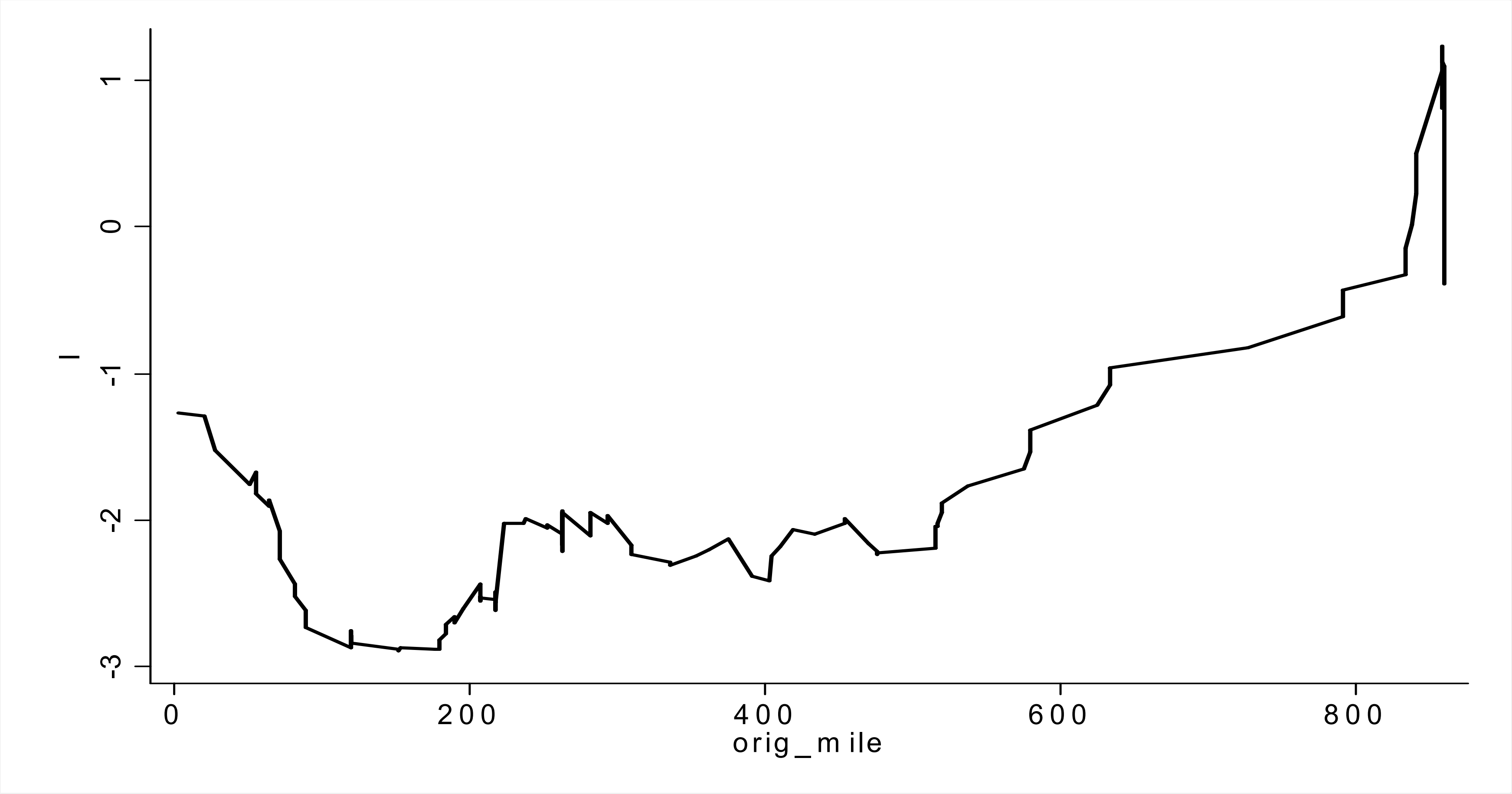
Locally Weighted Regression

- Window size 60:



Locally Weighted Regression

- Window size 80:



Varying Coefficients

- Based on these results, it appears that interacting the barge rate with river mile may be appropriate:
  - Linear Elasticity
  - Quadratic Elasticity
  - Cubic Elasticity

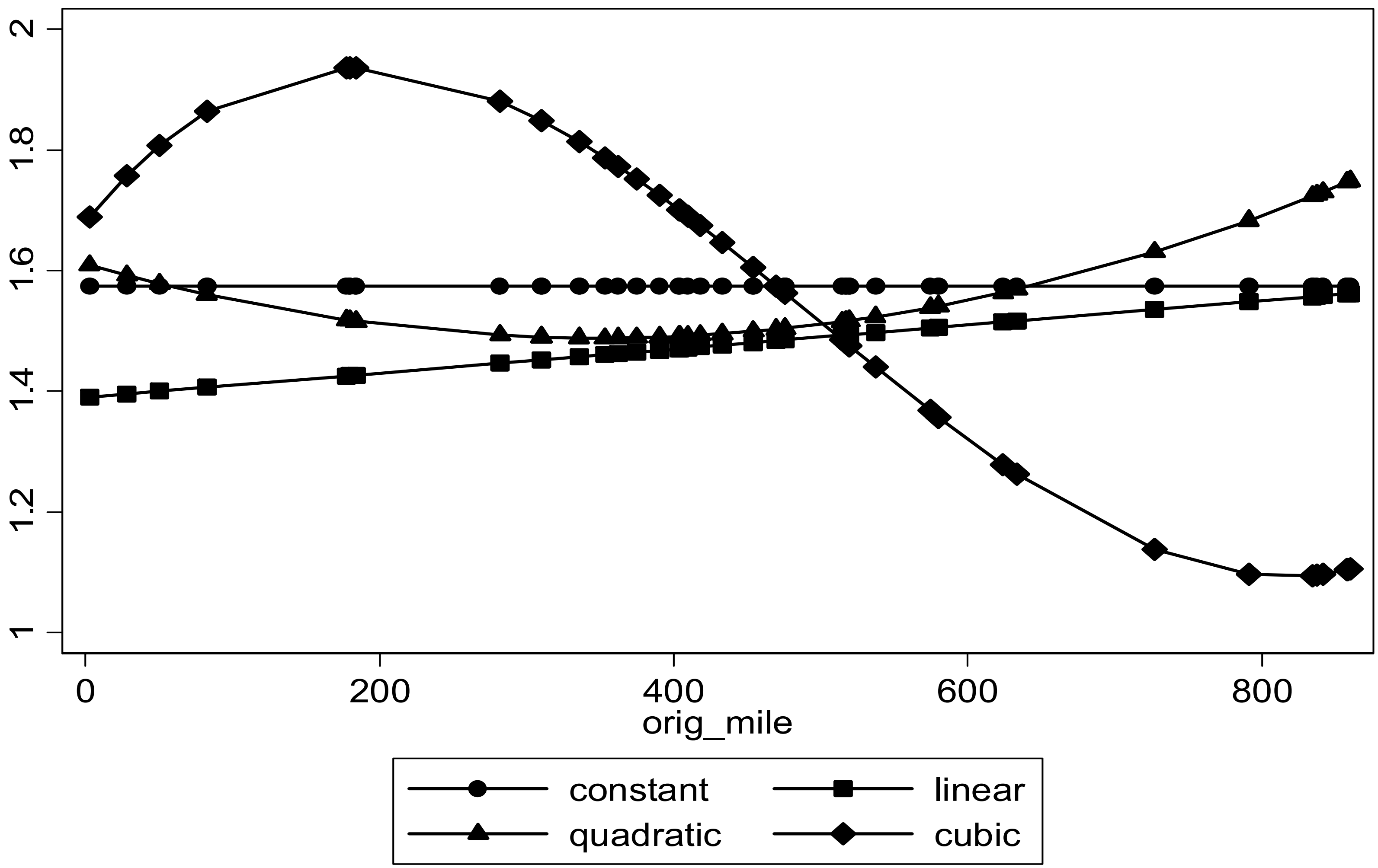
Upper Mississippi River

Model	Constant Estimate	Linear Estimate	Squared Estimate	Cubed Estimate
Constant Elasticity	-1.57**			
Linear Elasticity in River Mile	-1.39**	-0.0002		
Quadratic Elasticity in River Mile	-1.61**	0.0007	-0.000002	
Cubic Elasticity in River Mile	-1.68**	-0.003	0.00002	-0.00000002

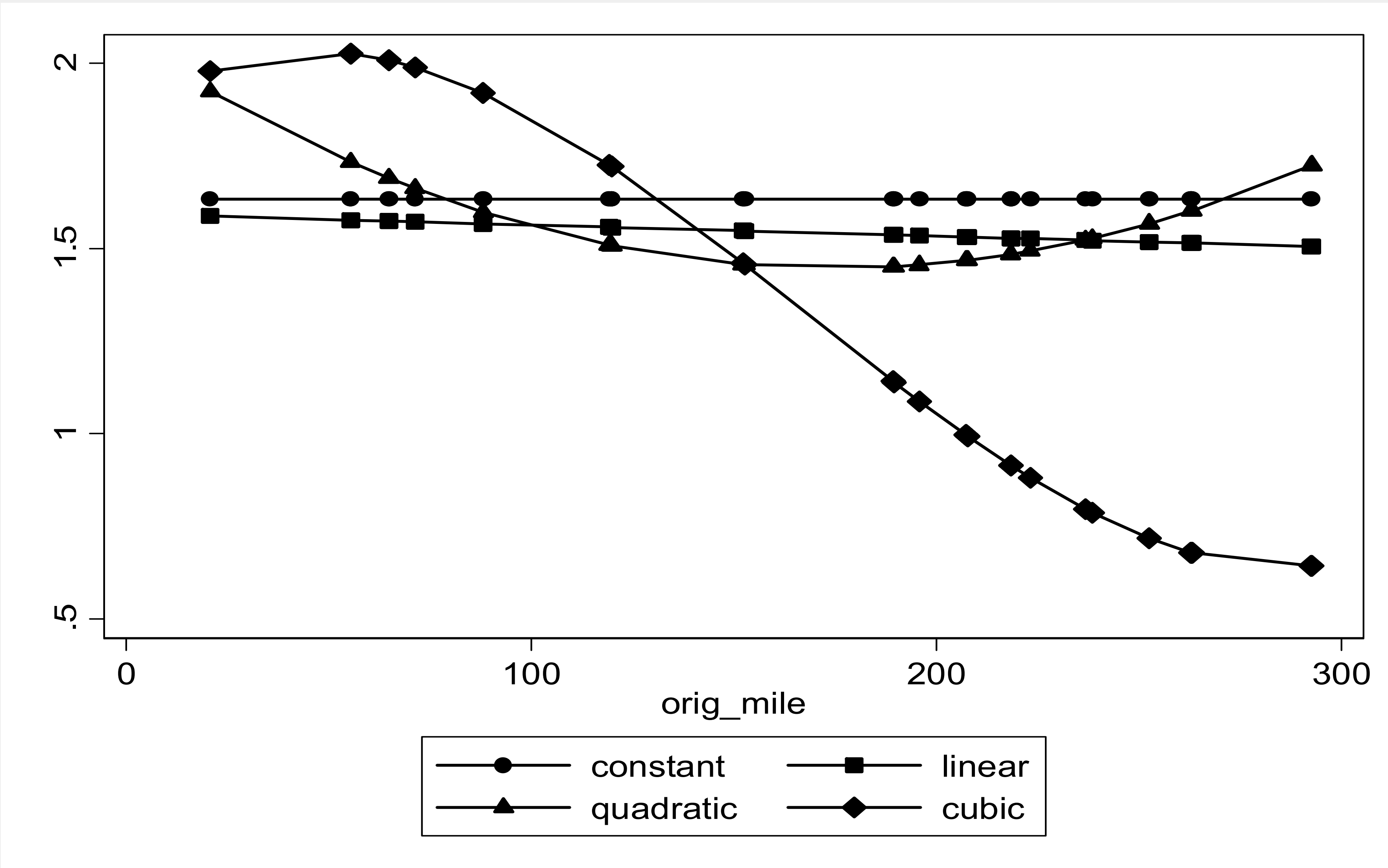
Illinois River

Model	Constant Estimate	Linear Estimate	Squared Estimate	Cubed Estimate
Constant Elasticity	-1.63***			
Linear Elasticity in River Mile	-1.59**	0.0003		
Quadratic Elasticity in River Mile	-2.06***	0.007*	-0.00004	
Cubic Elasticity in River Mile	-1.85***	-0.008	0.0002	-0.0000006

Upper Mississippi River



Illinois River



Endogenous Switch Points

- Conduct Break Point Tests for Every Possible Segmentation of the Waterway System
  - Identify the largest statistically significant break point and start over

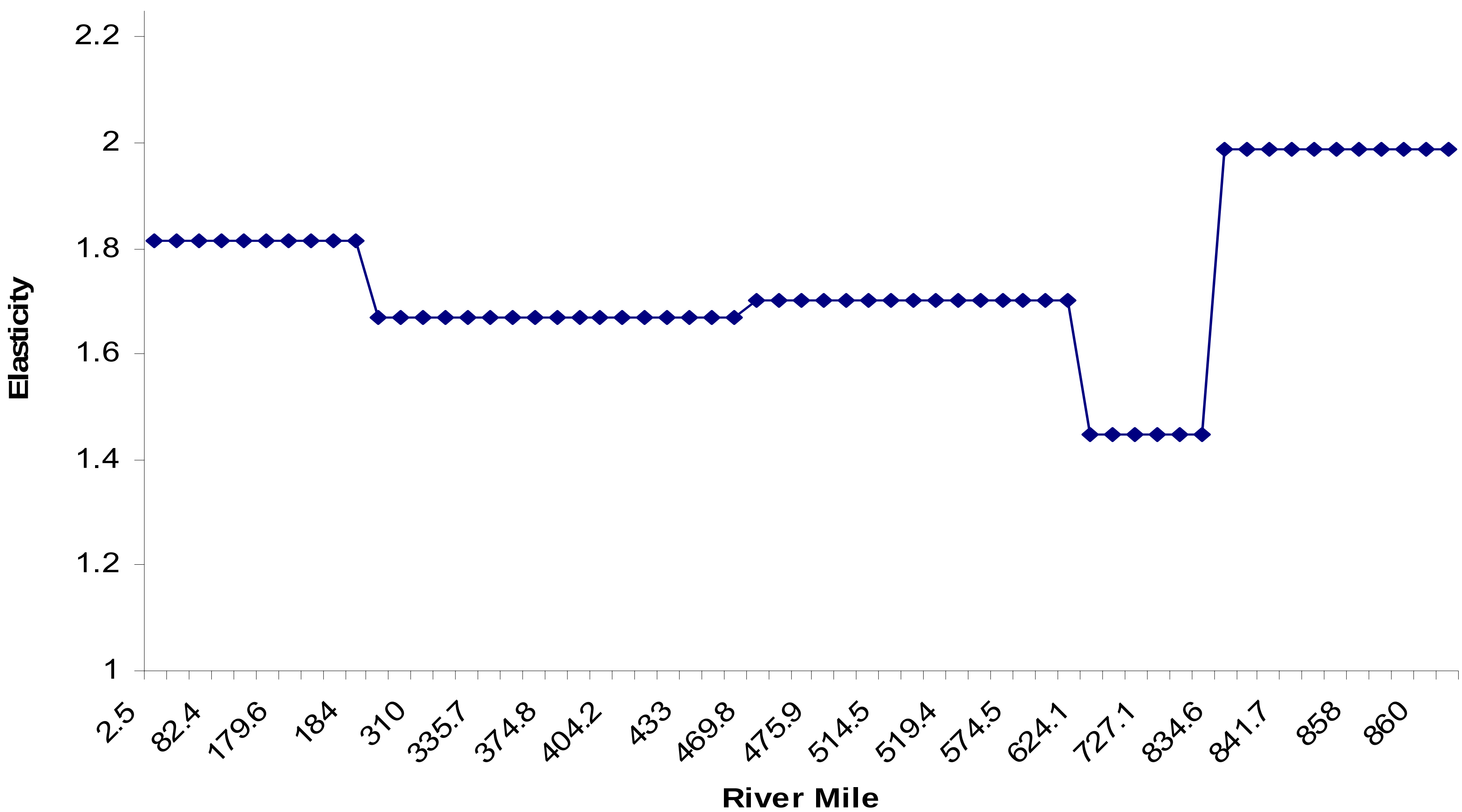
Break Points Found

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)

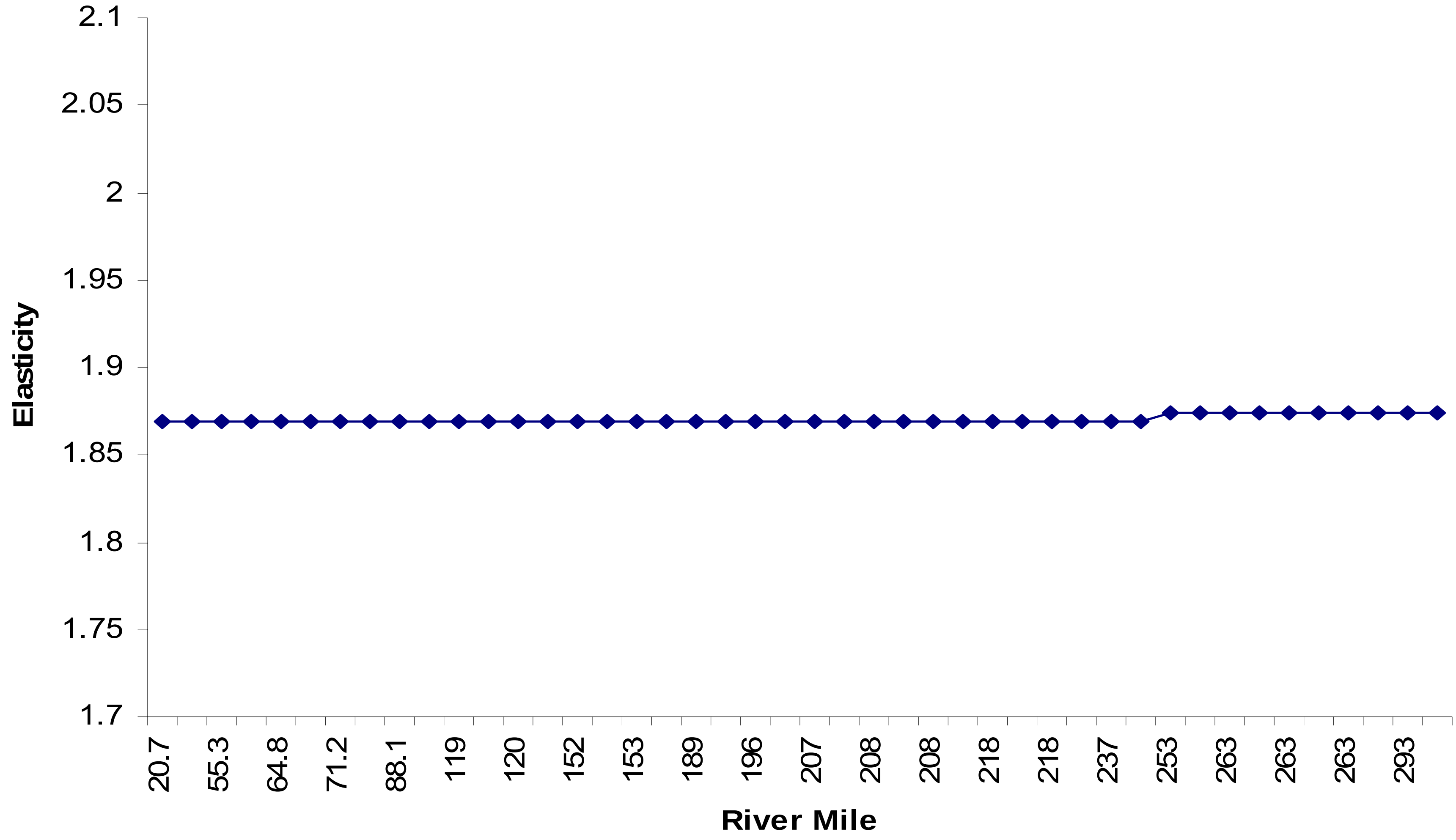
Elasticity Estimates Using Break Points

Upper Mississippi River					
	Below Lock 27	Between Locks 27 & 16	Between Locks 16 & 10	Between Locks 10 & 2	Above Lock 2
Elasticity	-1.815*** (0.640)	-1.668*** (0.611)	-1.702*** (0.604)	-1.448** (0.608)	-1.987*** (0.617)
Illinois River					
	Illinois River Below Lock 5	Illinois River Above Lock 5			
Elasticity	-1.869*** (0.611)	-1.874*** (0.618)			

Elasticity Estimates for the Upper Mississippi Using Break Points



Elasticity Estimates for the Illinois Using Break Points



Spatial Autocorrelation

- Because of the nature of the data, the errors of the elevators may be correlated spatially due to unobservable local shocks
- Therefore, a spatial autocorrelation model is used:

$$y = X\beta + \varepsilon$$
$$\text{where } \varepsilon = \lambda W \varepsilon + u$$

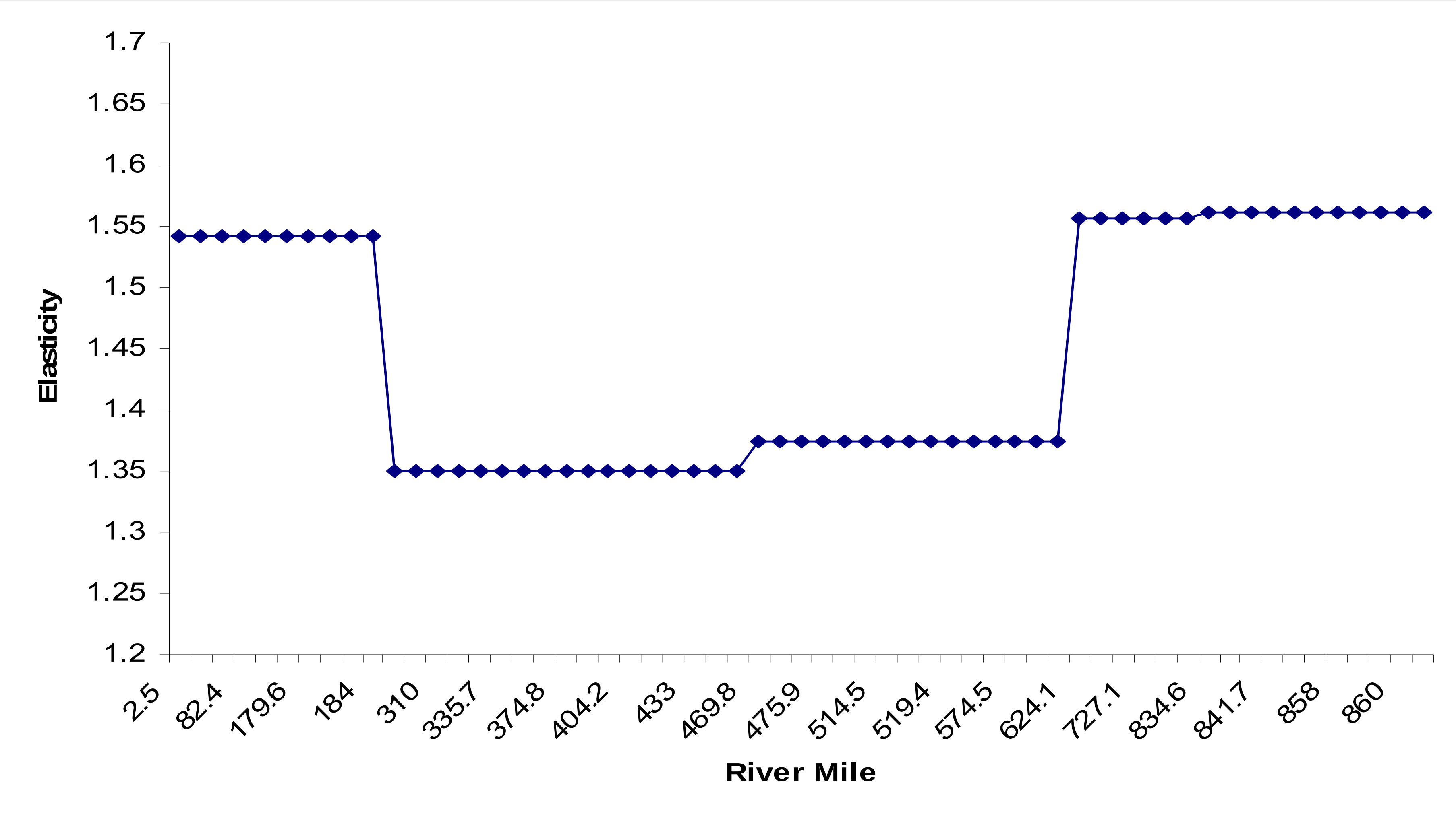
Spatial Autocorrelation

- Notice that this is no different than traditional OLS techniques with the exception of the error term which is augmented by $\lambda W \varepsilon$, where W is given by:

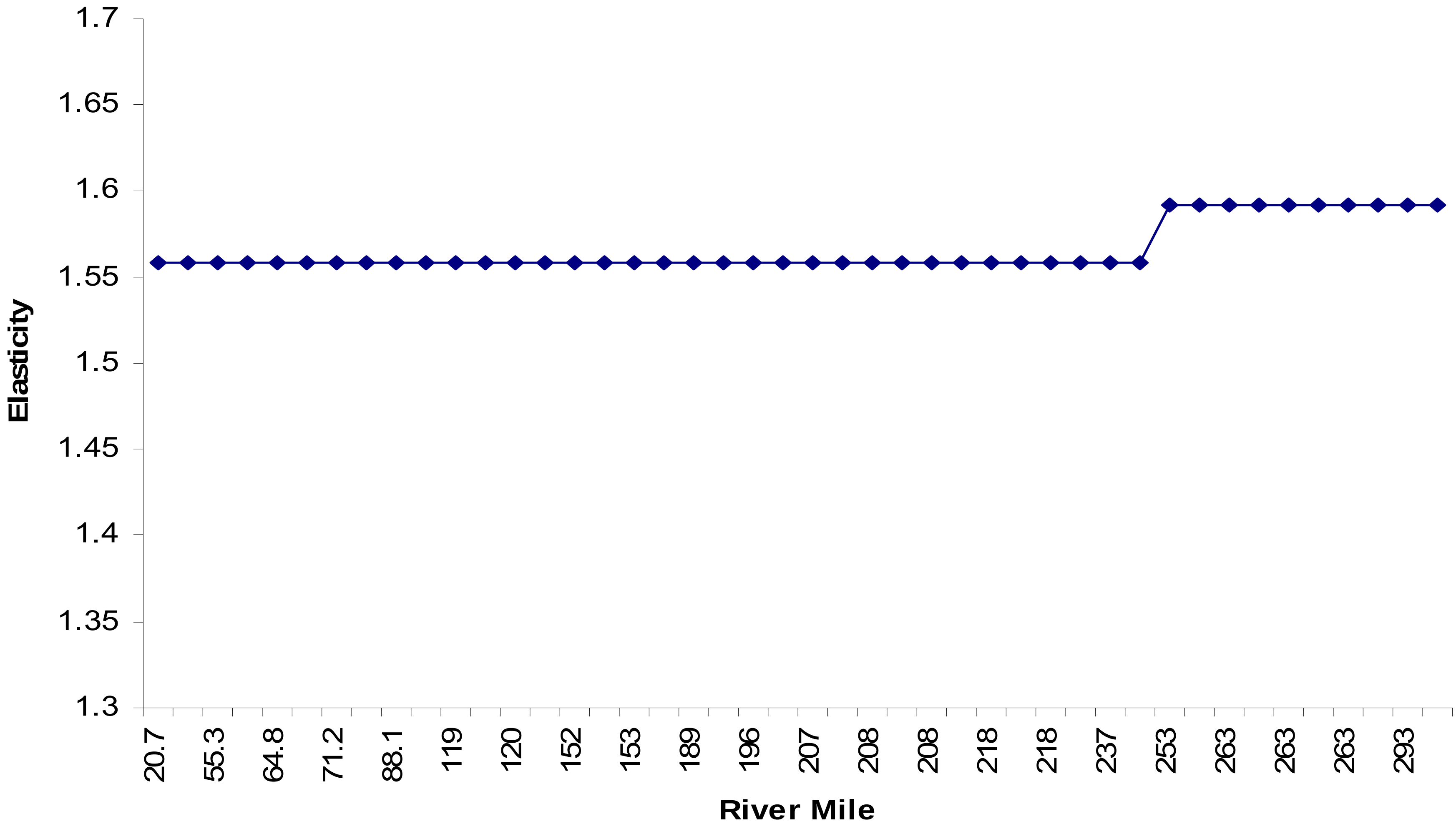
$$W_{i,j} = \begin{cases} 0 \quad if \quad i = j \\ \dfrac{1}{1 + d_{i,j}} \quad if \quad i \neq j \end{cases}$$

  – where *di,j* is the degree of contiguity between pools i and j

Elasticity Estimates for the Upper Mississippi Using the Spatial Autocorrelation Model



Elasticity Estimates for the Illinois Using the Spatial Autocorrelation Model



Spatial Autocorrelation

- The results of the spatial autocorrelation model are robust to the specification of the weighting matrix used, and are qualitatively similar to those found previously
- Additionally, tests for the appropriateness of the spatial autocorrelation model show that it is not warranted
  - Meaning that the observable spatial variables are controlling for regional differences in barge transportation demand

Conclusion

- Developed a model of transportation demand and the interrelated supply decisions of agricultural shippers over a geographic space
  - Combining the spatial literature with the transportation demand literature
- Estimated demand elasticities of -1.35 to -2
  - Stark contrast to assumptions of planning models
- Examined the possibility of non-constant elasticity
- Examined the possibility of the error terms being spatially correlated