Market Power in Transportation: Spatial Equilibrium under Bertrand Competition *

Simon P. Anderson† and Wesley W. Wilson‡

June 2014, revised September 2014

Abstract

We examine spatial competition along a waterway when shippers are distributed over space. Competition is between barge and rail companies and among barge companies. Equilibrium prices are derived for two variations: oligopolistic rivalry between barge and rail operators, and oligopolistic rivalry among barge operators with terminals located at different points on the waterway. In the first variant, each mode has an advantage over some shippers and transporters' overprice cost advantages (price differences are too small in equilibrium). The second variant delivers a "chain-linked" system of markets, whereby cost changes in one market are passed through equilibrium prices to other markets. Barge operators with cost advantages parlay these into market size advantages.

*We would like to thank the Navigation Economic Technologies (NETS) program for support. NETS was an Institute for Water Resources research program in the Army Corps of Engineers to enhance its mission in assessing waterway investments. This research was one of the projects: others can be found on www.corpsnets.us. We thank two anonymous referees and Andre de Palma for their constructive and clarifying comments.

†Department of Economics, University of Virginia. Anderson would like to acknowledge his debt to Richard Arnott for both supervising his PhD thesis, and for Richard's continual insights and inspiration into spatial and urban economics.

‡Department of Economics, University of Oregon.

1 Introduction

Suppliers of transportation have facilities to serve demanders located over geographic space, and spatial differences give rise to market power. We develop a model of equilibrium prices that explicitly recognizes the spatial heterogeneity of suppliers and demanders of transportation. The suppliers of transportation services offer rates from different locations to the final market(s). The demanders (or shippers) also are located at different points in space and as such have heterogeneous preferences across suppliers: ceteris paribus, a closer supplier is preferred. This latter feature imbues the suppliers with market power over those shippers located close by. We consider oligopolistic rivalry first between barge and rail and then among barge companies with spatial location differences. We examine the implications of spatial heterogeneity and market power on the effects of transportation infrastructure investment.

Two main variants are considered in order to address two different aspects of market power in spatially extenuated markets, namely, competition with alternative modes and competition with other operators in the same mode. We first set out the competitive version of the two variants, assuming that modes are priced at marginal cost. We then address market power in the transport sector by assuming that transport rates are set in a non-cooperative equilibrium by operators that have market power due to spatial proximity to some shippers. Even though competition is in prices (the "Bertrand" assumption), equilibrium prices are not set at own marginal cost or rival marginal cost (this is in contrast with spatially discriminatory Bertrand price equilibrium, as analyzed in Anderson and Wilson, 2008). The reason is that transport operators have some market power by dint of their closer location for some of the shippers, and they also are assumed to set a single rate for all shippers served (the no discrimination assumption).

In the first variant of the model, shippers face a mode choice of whether to ship by rail or river, and both modes are operated under market power. We find that whichever mode is cheaper (in terms of fundamental cost) is priced lower to shippers, and so attract more users. However, it will also carry a higher mark-up. This latter propensity of operators to overprice (resting on the laurels of a cost advantage) entails a market failure in the allocation of shippers to modes. Specifically, the fundamentally cheaper mode is actually under-utilized in equilibrium.[1] As we demonstrate, the social value of cost reductions for a mode e.g., barge exceeds the price reduction measured over shippers, but still falls short of that which would be realized if both rail and barge markets were competitive. Thus, only a portion of the cost reduction is passed on to shippers.

The second variant of the model is complementary to the first. Shippers can choose the transport provider to choose within a given mode (e.g., which barge operator). Competition by barge operators then gives rise to a market structure in which markets are vertically stacked.[2] Barge operators compete with their nearest neighbors upstream and downstream. Their interactions lead to an equilibrium in which all markets are "chain-linked" as each neighboring market is affected by its neighbors.

The primary purpose of the paper is to introduce a model of imperfect competition among modes of transportation operating over a network. In the model, firms compete for demanders located over space and are supplied by both rail and barge. This framework is central to assessing the benefits and costs of infrastructure investments such as locks. Currently, waterway policy-makers use a single-mode competitive model to judge benefits. Yet, there are a number of studies (e.g., MacDonald, 1987, Anderson and Wilson, 2008) which point to

[1]Similar results were derived by Anderson and de Palma (2001) in a much different context, namely a logit demand model where firms differ by the quality of the product offered. To the best of our knowledge, these results have not been developed in the spatial context.

[2]A somewhat similar spatial demand system is set up for Cournot competition in Anderson and Wilson (2005).

the effects of inter-modal competition on prices. Still others (e.g., Train and Wilson, 2004, 2008a, 2008b) examine shippers' choices and find that markets (i.e., rail and barge) are connected through the demand side. In the present work, we examine the effects of market power over the network both within a mode as well as between modes.

Our work is motivated by the need to calculate benefits of waterway investment by planners in the U.S. but may be applicable in other cases as well. The U.S. Army Corps of Engineers maintain and manage the U.S. waterway system (see the map in the Appendix). The inland waterway system has a network of about 12,000 miles, and handles about 300 billion ton-miles annually (Vachal et al., 2005). The commodities transported are generally bulk commodities (e.g., agricultural, coal, petroleum) and composition varies across rivers - the Upper Mississippi downstream traffic is dominated by agricultural movements, Ohio River traffic is dominated by coal, etc.

Demand derives from spatially distributed shippers that make modal decisions which can and do vary over locations. Supply is provided by truck, rail and barge. While there are a large number of trucking firms, there are only seven major railroads with whom barge companies compete with for longer haul distances. There are large numbers of barge companies that provide service. However, the number of water carriers varies across rivers and within rivers. For example, supply on the Columbia-Snake River is dominated by a single carrier which competes vigorously with railroads (which fits well with the model presented in Section 3).

We also consider barge-barge competition. Indeed, while the number of barge companies that operate in the U.S. is seemingly large (Vachal et al., 2005), they tend to be somewhat specialized in location and service. Using data described in Wilson (2006) that pertain to the Upper Mississippi, we are able to shed more light. Those data consist of movements through the 29 locks of the Upper Mississippi waterway for the year 2000. There are 83 companies that haul commodities southbound. For overall traffic (all locks), the market shares are generally quite small but can be as large as 24 percent. In terms of standard market structure measures, the four firm concentration ratio for traffic passing through the locks is about 66 percent, with a Herfindahl index of 1253. At the lock level, a more narrow market definition, the number of carriers ranges from two to sixty-seven at the 29 locks on the Mississippi waterway. The four firm concentration level ranges from 60 percent to 100 percent, and the Herfindahl ranges from 1189 to 9851 with an average value of 2179. It is clear that, based on these figures, the level of competition varies widely along the river. In some locations, the number of carriers is quite small, while in other locations the number of carriers is larger, but the overall indicators of concentration does point to the potential for barge-barge competition addressed in Section 4.

The next section sets out the basic model. Section 3 analyzes the first variant (rail vs. barge), while Section 4 gives the set-up and results for the second variant (intra-barge competition). Section 5 offers some conclusions.

2 The benchmark template for barge-rail and barge-barge rivalry

The geography of the benchmark model is shown in Figure 1. There is a river running from the North to the South along the y-axis (i.e., $x = 0$). Assume that the shippers are located with uniform density over a region of width δ contiguous to the river (this can be thought of as a river valley, say, of fertile land). In the first variant, there is also a parallel railway line at $x = \delta > 0$ (the other side of the shippers' locations). There are river terminals at latitudes y_i, $i = 1, ..., n$, indexed so that a higher value of y_i indicates a location further North. We denote by $\bar{b}_i$ the cost of shipping a unit of the commodity from latitude y_i by river (i.e., by barge) all the way to the final transshipment point (in this case, the southern-most point).[3] Per unit shipping costs rise with the distance shipped, so that $\bar{b}_i < \bar{b}_j$ as $i < j$. These costs denote the actual costs faced by the transport operators. The latter set rates above costs to shippers since the operators have market power.[4]

INSERT FIGURE 1. Economic Geography for Barge-Rail Competition

Likewise, in the first variant of the model when we focus on competition between barge and rail, the cost of shipping a unit of the commodity from latitude y_i by rail to the final transshipment point is $\bar{r}_i$, with $\bar{r}_i < \bar{r}_j$ with $i < j$. It is assumed that each river terminal has a parallel rail terminal (i.e., at the same latitude as the river terminal).[5] We assume that these locations are exogenous. We further assume that $\bar{b}_i < \bar{r}_i$ so that rail transportation is more costly. Since the rail terminal may be closer to some shippers' locations than the river terminal, this does not preclude rail being used by shippers. Moreover, shipping prices are determined by barge operators and by rail companies, and, in equilibrium, these prices reflect a trade-off between volume transported and mark-up earned. The first objective is to determine how these prices reflect competitive conditions and costs.

To focus on rail-barge rivalry, we assume away rivalry among barge operators (which is the focus of the next Section.) This we do by assuming that the latitudinal boundary between neighboring barge operators is fixed at $\bar{y}_i$, with $\bar{y}_i \in (y_i, y_{i-1})$. This assumption prevents competition across the latitudinal

[3]Much of our work is motivated by agricultural shipments on the Mississippi to New Orleans for export. Ninety percent of corn shipments that originate upstream terminate in the New Orleans area (Boyer and Wilson, 2005).

[4]Thus, we refer to the prices paid by shippers as rates (even though these are the costs paid by the shippers), and we reserve the term "costs" for the fundamental costs.

[5]This we do in order to bring out the basic tensions of competitive rivalry in the clearest manner. The qualitative results should not change if the rail terminals are at different latitudes, though the demand expressions and the equilibrium analysis would be substantially more cumbersome.

boundary and allows it only between rail and barge within a given band (or stripe) of latitudes.[6]

The commodity is trucked from the hinterland to either a river terminal or a rail terminal, at rate t per unit per mile. As noted above, we initially assume that shippers must ship to the closer latitude (this will be addressed separately as the main focus of attention in the second variant of the model). Truck transportation follows the block metric (distance between two points is measured as the sum of their vertical and horizontal displacements) and so, for given rates charged for rail and barge transportation, the hinterland will be split into blocks corresponding to demand regions: blocks nearest the river will use barge transportation. A further rationale for analyzing this set-up is that it corresponds most closely to the basic Samuelson-Takayama-Judge (STJ) assumption that catchment areas are fixed, but at the same time it allows for competition by transportation mode within each "region" for shippers.[7]

Figure 1 is drawn for the case of Barge-Rail competition of the next Section, but the only major change for the Barge-Barge competition model of Section 4 is that the railway is not present and competition is between neighboring barge terminals instead. For the Barge-Rail competition case, as illustrated, competition is between barge and rail for each given strip of territory between given latitudes: all shippers between $\bar{y}_i$ and $\bar{y}_{i+1}$ must choose between the river terminal at latitude y_i (and longitude $x = 0$) and the rail terminal at latitude y_i (and longitude $x = \delta$).

Finding equilibrium prices within each region requires the determination of transporters' profits as function of the prices charged by themselves and their

[6] For example, $\bar{y}_i$ could be the location of a lock, and we invoke a "no-lock-jumping" assumption. Alternatively, we could use the market boundaries defined from perfectly competitive conditions between barge operators. Then the boundary, as derived below, is given as $\bar{y}_i = \frac{\bar{b}_{i+1} - \bar{b}_i}{2t} + \frac{y_{i+1} + y_i}{2}$.

[7] We consider this connection in greater detail in related work (Anderson and Wilson, 2004, 2007).

rivals. This means that we must first find transportation demand as a function of prices. The next two sections pick up at this point for their respective models.

3 Barge-rail rivalry

In this variant, we concentrate on competition between modes, leaving intra-mode competition for the next variant. Accordingly, we assume that the latitude decision is fixed exogenously: for concreteness, assume that all shippers between $\bar{y}_i$ and $\bar{y}_{i+1}$ choose either to ship from the river or rail terminal at latitude y_i (so the only choice shippers must make is between river and rail), with $y_i \in (\bar{y}_i, \bar{y}_{i+1})$. Under these assumptions, the market at any latitude is determined by the location $\hat{x}_i$ of the shipper indifferent between the relevant rail and river options.

Let r_i be the price charged at latitude y_i for rail transport (per unit)[8] and b_i be the corresponding price for river transport. Shipping by river from longitude x incurs a price of $r_i + t\,|x|$ (ignoring the North-South trucking cost to the relevant latitude, latitude y_i, since this is common to both options).[9] Shipping by rail (again net of the trucking cost to latitude y_i) incurs a price of $b_i + t\,|\delta - x|$ from longitude x.

When there is perfect competition at each mode, the transport rates are $\bar{r}_i$ for rail and $\bar{b}_i$ for barge. The market split point is then given as the solution to $\bar{r}_i + t\,|\hat{x}_i| = \bar{b}_i + t\,|\delta - \hat{x}_i|$, i.e.,

$$\hat{x}_i = \frac{\delta}{2} + \frac{\bar{r}_i - \bar{b}_i}{2t}. \tag{1}$$

[8] Wilson (1996) considers rail pricing in the context of differentiated modes. In his model, the railroad chooses whether it wants the traffic and then how much can they charge. This latter is the maximum of the monopoly price or the price at which the railroad loses the traffic to another mode.

[9] That is, total trucking cost if the shipment is later taken by barge is $t\,|x| + t\,|y - y_i|$; if the shipment is later taken by rail, the total trucking cost is $t\,|x - \delta| + t\,|y - y_i|$. Since the term $t\,|y - y_i|$ is common, it may be ignored in determining the choice of mode for the final segment. This means that the market boundaries between barge and rail are vertical (North-South): the property follows from the block metric for transportation.

The situation is illustrated in Figure 2. The sloped lines represent the full price paid as a function of lateral distance from the terminals for barge and rail, incorporating the lateral trucking costs, giving the slopes at rate t. As illustrated, the barge rate is lower than the rail rate, so that the market split (at $\hat{x}_i$, East of δ) induces a larger market for barge than rail.

INSERT FIGURE 2. Barge-Rail Market Division (longitudinal split).

As should be clear from Figure 2, the relevant portion of Figure 1 is a horizontal line between rail and barge ports at latitude y_i. That is, the North-South components of Figure 1 are irrelevant in this simple setup. The market split relation in (1) indicates several properties. First, if barge and rail rates are equal, the market splits equally between modes. All shippers closer to the river ship from there, and all shippers closer to the rail terminal ship by rail. The market demand for barge decreases in its own price, and rises in the rival operator's price, so the two modes are substitutes for shippers. The rate of switch-over from one mode to another (the rate at which the marginal shipper transfers economic allegiance) is inversely proportional to the truck rate (the switch-over rate is 1/2t per dollar price difference) Thus, the higher the truck rate, the less responsive are shippers to switching in response to lower barge or rail rates. This natural property follows because as higher rates imply the share of barge and rail costs relative to overall costs decline, and this reduction reduces rate responsiveness.

The same properties hold when rates are set with market power, although then the rates are determined by the transport operators. These rates depend upon the basic costs, $\bar{r}_i$ and $\bar{b}_i$. For given rates, the market splits in region i at

$$\hat{x}_i = \frac{\delta}{2} + \frac{r_i - b_i}{2t}. \tag{2}$$

This differs from (1) only insofar as the competitive rates, $\bar{r}_i$ and $\bar{b}_i$, are now determined by transport operators as r_i and b_i (and so the basic picture in Figure 2 now holds with r_i and b_i in lieu of $\bar{r}_i$ and $\bar{b}_i$.)

The basic market power analysis is based on an asymmetric version of Hotelling's (1929) model.[10] In addition to considering the asymmetries, the current version is also distinctive for the comparison of stacked markets (and the variant in the next Section is distinctive for the analysis of rivalry between such stacked markets).

Given the demands, as embodied in (2), we can now turn to profits. For a barge operator operating from a river terminal at latitude y_i, profits are then given by:

$$\pi_{bi} = \left(b_i - \bar{b}_i\right)\hat{x}_i \tag{3}$$

which is the product of the mark-up and the demand. The barge operator thus faces a trade-off: the larger the mark-up, the lower the volume of sales, and vice versa. Similarly, profits for rail (operating from a river terminal at latitude y_i) are given by:

$$\pi_{ri} = (r_i - \bar{r}_i)(\delta - \hat{x}_i). \tag{4}$$

The first-order condition for determining the barge rate are then

$$\frac{\partial \pi_{bi}}{\partial b_i} = \hat{x}_i - \frac{\left(b_i - \bar{b}_i\right)}{2t} = 0. \tag{5}$$

The first term is the extra revenue on the existing customer base for a \$1 increase. The second one is the lost revenue (the mark-up) on the lost consumer base (which is lost at rate $1/2t$). The analogous first-order condition for the rail operator is:

$$\frac{\partial \pi_{ri}}{\partial r_i} = (\delta - \hat{x}_i) - \frac{(r_i - \bar{r}_i)}{2t} = 0. \tag{6}$$

[10] Hotelling's simple framework remains an enduring one that has attracted many researchers. Hotelling's approach furnished a canonical model not just for studying equilibrium locations, but also for simple product differentiation, political competition, marketing decisions, and a host of other applications. Some of these are detailed in Anderson (2005), and reviews of models in Hotelling's vein are found in Anderson, de Palma, and Thisse (1992, Chapter 8), Archibald, Eaton, and Lipsey (1989), Enke (1951), and Gabszewicz and Thisse (1992).

Note that the second-order conditions clearly hold (the profit functions are concave quadratic functions). The first-order conditions define the reaction functions for the operators. These reaction functions, and the associated equilibrium at their intersection, are illustrated in Figure 3. The Figure embodies the assumption that $\bar{r}_i$ exceeds $\bar{b}_i$: the fundamental cost per unit shipped is higher for rail than barge.

INSERT FIGURE 3. Reaction Functions and Equilibrium for Barge-Rail Formulation

Each reaction function embodies the property that a \$1 rise in its rival's transport rate will raise its own optimal (best reply) rate by 50 cents. Hence the equilibrium is unique and stable. Reaction functions slope up and so the transport rates are "strategic complements" (they move together).

The explicit equilibrium solution can be derived from the first-order conditions. We have from (5) and (6) above that $\hat{x}_i = \frac{(b_i - \bar{b}_i)}{2t}$ and $(\delta - \hat{x}_i) = \frac{(r_i - \bar{r}_i)}{2t}$. These are respectively rewritten as

$$b_i = 2t\hat{x}_i + \bar{b}_i \tag{7}$$

and

$$r_i = 2t\left(\delta - \hat{x}_i\right) + \bar{r}_i. \tag{8}$$

Then recall from (2) that $\hat{x}_i = \frac{\delta}{2} + \frac{r_i - b_i}{2t}$ which enables us to solve for $\hat{x}_i$ from the relations (7) and (8) above as:[11]

$$\hat{x}_i = \frac{\delta}{2} + \frac{\bar{r}_i - \bar{b}_i}{6t} \tag{9}$$

in equilibrium.[12] Note that the market splits at the mid-point under symmetry of fundamental costs. Note too that the solution is independent of monetary

[11] Since $\hat{x}_i = \frac{\delta}{2} + \frac{2t(\delta - 2\hat{x}_i) + \bar{r}_i - \bar{b}_i}{2t}$ or $3\hat{x}_i = \frac{3\delta}{2} + \frac{\bar{r}_i - \bar{b}_i}{2t}$ and hence (9) follows directly.

[12] If $\frac{\delta}{2} + \frac{\bar{r}_i - \bar{b}_i}{6t} \geq \delta$, then the whole market is served by the barge operator. Equivalently, the condition is written as $\bar{r}_i \geq \bar{b}_i + 3t\delta$.

measures and depends on the *ratio* of transport rates: if all transportation prices doubled, the solution does not change. Market power cushions the impact of fundamental cost changes: the equilibrium change is at rate 1/6t while the perfectly competitive counterpart is at rate 1/2t per dollar change in the fundamental costs.

We can now back out the equilibrium transport rates. In particular, since $b_i = 2t\hat{x}_i + \bar{b}_i$ then $b_i = t\left(\delta + \frac{\bar{r}_i - \bar{b}_i}{3t}\right) + \bar{b}_i$ or

$$b_i = t\delta + \frac{1}{3}\left(\bar{r}_i + 2\bar{b}_i\right). \tag{10}$$

This shows some interesting absorption properties. First, each \$3 rise in own shipping cost feeds through into a rise in equilibrium shipping rate charged of \$2. The transport provider absorbs the other \$1 itself for fear of giving up too much market to its rival. Likewise, an increase of \$3 in the rival's cost feeds through into an own price increase of \$1. The explanation follows from strategic complementarity (the property that the reaction functions slope up: see Figure 3 above).

Similarly, $r_i = 2t\left(\delta - \frac{\delta}{2} - \frac{\bar{r}_i - \bar{b}_i}{6t}\right) + \bar{r}_i$, or

$$r_i = t\delta + \frac{2\bar{r}_i + \bar{b}_i}{3}. \tag{11}$$

In particular, it can readily be seen that the operator with the lower cost of transport (i.e., whether $\bar{b}_i$ or $\bar{r}_i$ is lower) also has the lower price. Nonetheless, its mark-up is higher, it gets a greater fraction of the market, and its profit is also higher. These important properties are readily proved. The intuition is as follows. Suppose that barge transportation is less costly than rail. The barge operators use this advantage to increase mark-ups, but not so much as to reduce their market areas. Put another way, barge operators use their advantage to both enjoy higher mark-ups and larger markets; meaning that the prices they charge are still below the rail operators' prices.

These properties are reflected in smaller market areas than is optimal for barge (and larger market areas than is optimal for rail).[13] To see this, note that the socially optimal allocation involves both modes priced at cost, leading to an optimal allocation of

$$\hat{x}_i^o = \frac{\delta}{2} + \frac{\bar{r}_i - \bar{b}_i}{2t}. \tag{12}$$

Then, as long as $\bar{r}_i > \bar{b}_i$, we have $\hat{x}_i^o > \hat{x}_i$. This follows since $\hat{x}_i = \frac{\delta}{2} + \frac{\bar{r}_i - \bar{b}_i}{6t}$ by (9).

We can next find the implications for prices as a function of distance. Suppose, for illustration, that the fundamental price for both rail and barge rise with distance, and that the rail price is proportional to the barge one, with constant of proportionality $\alpha > 1$ (so that rail costs are higher than barge costs). Then we find that the rail price charged always exceeds the barge price, although the barge mark-up is higher. Furthermore, the barge catchment area is larger the further away from the terminal market. That is, barge serves a larger fraction of the shippers the closer to the source of the river. To see this latter property, it suffices to write the equilibrium market share relation as (using (9)):

$$\hat{x}_i = \frac{\delta}{2} + \frac{\bar{r}_i - \bar{b}_i}{6t} = \frac{\delta}{2} + \frac{(\alpha - 1)\,\bar{b}_i}{6t}.$$

This is clearly increasing in $\bar{b}_i$, and hence in distance.[14] However, the optimal allocation between barge and rail is

$$\hat{x}_i^o = \frac{\delta}{2} + \frac{(\alpha - 1)\,\bar{b}_i}{2t}.$$

This means that market power in the transportation sector induces the distortion that the market area for barge is too small (since the mark-up is too big).

[13] Recall though we have assumed that both the barge provider and the railway have equal market power. This assumption drives the result. If, instead, we assumed that barge operators priced perfectly competitively, rail markets would be too small (and barge markets too large), but the "fault" would lie squarely with the rail operator for pricing too high. In an earlier paper, Anderson and Wilson (2008), we covered just such a case and derived this result.

[14] It is apparent from the formula that the whole market is served by barge as long as $\frac{(\alpha-1)\bar{b}_i}{6t} \geq \frac{\delta}{2}$.

Since barge has been assumed to be cheaper, and market power has been taken as equally strong on both sides of the market, the barge sector overprices its advantage. We should note that this analysis has simply assumed that market power is equally strong in the barge market as in the rail market, with the purpose of theoretically deriving the efficiency implications of market power. If, instead, the barge market is taken as perfectly competitive while the rail market has the market power, the rail market is over-priced relative to barge and it is the rail market that is too small.

We can also derive the implications of a transportation cost reduction, for concreteness, a decrease in the cost of barge shipping. This is manifest as a reduction in $\bar{b}_i$. This change induces a reduction in the price charged for barge transportation that improves the well-being of shippers using barge. Since the price reduction is less than the cost reduction, the barge operators are better off, enjoying greater profits. However, rail operators are worse off because they face tough competition. Rail operators' profits fall for two reasons. First, they face lower prices from the rival mode, inducing lower profits, and second, they have smaller markets served. Shippers in the rail segment also gain from the cost improvement in the barge sector. This is because they pay lower prices for rail, even though there is no cost reduction there. The tougher competition induces lower prices for shippers. Hence, the social value of the improvement exceeds the price reduction as measured over the barge shippers. Nonetheless, the social value falls short of what it would be if there were perfect competition. This is because the allocation remains distorted: the cost reduction is only partially passed on to the shippers, and hence only partially matched by the rail operators.

3.1 Introducing time costs

In the model so far, shipper choices are driven by prices alone. Time enters only through the costs of traveling through a lock. There is, of course, a history of research that indicates shippers care not only about rates, but also quality of service, which includes transit times and reliability (see, for example, Train and Wilson, 2004, 2008a, 2008b). Indeed, it is commonly recognized that barge rates are lower than rail which are lower than truck. While costs are lower in the same direction, the service by barge is slower than rail which is slower than truck.

We now show how the basic model is readily amended to allow shipper choices to also depend on differential time costs across transport modes. The basic insights and take-aways still hold with appropriate reinterpretation of parameters.

To see this, we now suppose that time costs for barge and rail from latitude y_i take monetary equivalents c_i^b and c_i^r respectively. Notice that these could vary across the shipping season (just as the base opportunity costs $\bar{b}_i$ and $\bar{r}_i$ can vary too), so that equilibrium rates will accordingly vary as a consequence.

The "full prices" to shippers (denoted by f superscripts, and exclusive of the trucking cost to the relevant terminal) from barge and rail comprise the sum of money and time costs. Thus full prices paid are $b_i^f = b_i + c_i^b$ and $r_i^f = r_i + c_i^r$ respectively. The market split condition (2) is as before except now with full prices in place of the former time-cost exclusive ones. Likewise, we can write the operators' profit margins as $\left(b_i - \bar{b}_i\right) = \left(b_i^f - \left(\bar{b}_i + c_i^b\right)\right)$ and likewise for rail. The duopoly game for choosing rates (b_i and r_i) is strategically equivalent to choosing them full prices. Therefore the profit functions we had before, (3) and (4), take the same form and have the same solutions. The difference is that the solutions corresponding to and are now in terms of full prices, and costs are now "full" costs, i.e., the sum of costs to shippers and the monetized time costs borne by shippers. That is, the solution is (using (10) and (11))

$$b_i^f = t\delta + \frac{(\bar{r}_i + c_i^r) + 2\left(\bar{b}_i + c_i^b\right)}{3} \tag{13}$$

and

$$r_i^f = t\delta + \frac{2\left(\bar{r}_i + c_i^r\right) + \left(\bar{b}_i + c_i^b\right)}{3}. \tag{14}$$

Rates received by transport operators are found by subtracting the time costs. That is, we now have

$$b_i = t\delta + \frac{\bar{r}_i + 2\bar{b}_i + c_i^r - c_i^b}{3}$$

and

$$r_i = t\delta + \frac{2\bar{r}_i + \bar{b}_i + c_i^b - c_i^r}{3}.$$

Hence these rates pass on transport costs in the same manner that they did in the simpler incarnation (which is seen as the special case $c_i^b = c_i^r$). The rates also now embody time cost advantages, absorbing a fraction (a third) of own cost, and charging the same fraction for the rival mode's time cost. Thus, as noted above, if barge has a higher time cost, then this feeds through into a higher rail rate and a lower barge rate.

4 Barge-barge competition

We now turn to the case of barge-barge competition. For this purpose, we assume that railroads do not exist, which allows us to focus directly on rivalry amongst barge carriers. Assume again that the shippers are located with uniform density over a region of width δ contiguous to the river.[15] The new economic geography is depicted in Figure 4 for the case of perfectly competitive operators. The difference with Figure 1 is that there is no competition from rail

[15]More complex versions of the model would have reservation prices that would bind for some shippers, etc. See e.g., Böckem (1994) for an analysis with symmetric firms.

and the market boundaries are endogenously determined. We also explicitly allow for shippers at the most Southerly locations to ship directly by truck to the terminal market, and for shippers at the most Northerly locations to ship to an alternative market, as described below.

INSERT FIGURE 4. Economic Geography for Barge-Barge Model.

First, suppose that barge operators were to price at marginal cost (this is the perfect competition back-cloth benchmark). Then $\bar{b}_i$ is the price of barge transportation from y_i to the final market. Neighboring barge markets are separated at the latitude $\bar{y}_i$ as determined by

$$\bar{b}_{i-1} + t\left[\bar{y}_i - y_{i-1}\right] = \bar{b}_i + t\left[y_i - \bar{y}_i\right], \qquad i = 1, ..., n \tag{15}$$

where the left hand side is the cost for a riverside shipper at $\bar{y}_i$ to ship from the next river terminal to the South, at y_{i-1}, and the right hand side is the cost for a riverside shipper at $\bar{y}_i$ to ship from the next river terminal to the North, at y_i. Hence, $\bar{y}_i$ is determined as

$$\bar{y}_i = \frac{\bar{b}_i - \bar{b}_{i-1}}{2t} + \frac{y_i + y_{i-1}}{2}.$$

Shippers at the lowest latitudes will just ship by truck to the final market. The farthest south barge operator therefore faces competition from truck for the haul. The southern latitudinal margin of competition for its market, $\bar{y}_1$, is therefore determined endogenously by its shipping cost, $\bar{b}_1$, according to the indifference condition for the shippers along the boundary, namely $t\bar{y}_1 = t\left(y_1 - \bar{y}_1\right) + \bar{b}_1$, where the LHS is the north-south cost of trucking from the boundary, and the RHS is the cost of trucking north to the barge terminal and then taking barge down the river. Notice that our assumption of the simple block metric for truck transport is instrumental in delivering a clean lateral market boundary. Furthermore, notice that the equation for $\bar{y}_1$ is commensurate with the ones for the other margins of competition by setting $b_0 = 0$ (so there is no market power held over shippers in the truck market), so that

$$\bar{y}_1 = \frac{\bar{b}_1}{2t} + \frac{y_1}{2}.$$

At the other end, for symmetry with this treatment, suppose that the terminal the farthest to the North ships to an alternative final market (the Pacific Northwest, say). Assume that this rate is set perfectly competitively, at $\bar{b}_{n+1}$. Then the furthest north market boundary is given as

$$\bar{y}_{n+1} = \frac{\bar{b}_{n+1} - \bar{b}_n}{2t} + \frac{y_{n+1} + y_n}{2}.$$

The situation is quite similar under rivalrous barge operators exercising spatial market power. Then neighboring barge markets are separated at the latitude $\hat{y}_i$ as determined by

$$b_{i-1} + t\left[\hat{y}_i - y_{i-1}\right] = b_i + t\left[y_i - \hat{y}_i\right].$$

Again, the left hand side is the cost for a riverside shipper at $\hat{y}_i$ to ship from the next river terminal South (at y_{i-1}); the right hand side is the cost for a riverside shipper at $\hat{y}_i$ to ship from the next river terminal North (at y_i). Now $\hat{y}_i$ is

$$\hat{y}_i = \frac{b_i - b_{i-1}}{2t} + \frac{y_i + y_{i-1}}{2}.$$

For the lowest market (the one farthest to the South), as explained above, $b_0 = 0$ and

$$\hat{y}_1 = \frac{b_1}{2t} + \frac{y_1}{2}.$$

Likewise, given $\bar{b}_{n+1}$, the furthest North market boundary is

$$\hat{y}_{n+1} = \frac{\bar{b}_{n+1} - b_n}{2t} + \frac{y_{n+1} + y_n}{2}.$$

We can now write out the profits for a barge operator operating from a river terminal at latitude y_i, $i = 1, ...n$. These are then given by[16]:

$$\pi_{bi} = \left(b_i - \bar{b}_i\right)(\hat{y}_{i+1} - \hat{y}_i) \tag{16}$$

which is the product of the mark-up and the demand. The barge operator thus faces a trade-off: the larger the mark-up, the lower the volume of sales, and vice versa. The first-order condition for determining the barge rate are then

$$\frac{\partial \pi_{bi}}{\partial b_i} = (\hat{y}_{i+1} - \hat{y}_i) - \frac{\left(b_i - \bar{b}_i\right)}{4t} = 0. \tag{17}$$

The first term is the extra revenue on the existing customer base for a \$1 increase. The second is the value of lost shippers: they switch at rate 1/4t counting the two sides at which they switch. The formulation already embodies the property that large markets are associated to high mark-ups.

We can now solve for the market boundaries to yield

$$\left(\frac{b_{i+1} - b_i}{2t} + \frac{y_{i+1} + y_i}{2} - \frac{b_i - b_{i-1}}{2t} - \frac{y_i + y_{i-1}}{2}\right) = \frac{\left(b_i - \bar{b}_i\right)}{4t}.$$

Simplifying,

$$5b_i - 2\left(b_{i+1} + b_{i-1}\right) = 2t\left(y_{i+1} - y_{i-1}\right) + \bar{b}_i.$$

Divide through by 5 and then denote the Left-Hand-Side by $M_i = \frac{2t(y_{i+1} - y_{i-1}) + \bar{b}_i}{5}$, $i = 1, ...n$. Also, denote the constant coefficient that comes from the structure of the problem as $\alpha = \frac{2}{5}$, in order to see clearly the structure. Then these equations may be written

$$b_i - \alpha\left(b_{i+1} + b_{i-1}\right) = M_i, \qquad i = 1, ..., n.$$

Although each barge operator competes directly only with its nearest neighbors upstream and downstream, markets are chain-linked through their interaction. Then we can write the system of stacked demands in matrix form as

[16] We neglect here the factor of proportionality that represents the width of the market, δ, and the density of shippers. The product of these two factors has effectively been normalized.

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -\alpha & 1 & -\alpha & 0 & 0 & 0 & 0 & 0 \\ 0 & -\alpha & 1 & -\alpha & 0 & 0 & 0 & 0 \\ . & 0 & -\alpha & 1 & -\alpha & 0 & 0 & . \\ . & . & . & . & . & . & . & . \\ . & 0 & 0 & 0 & -\alpha & 1 & -\alpha & 0 \\ 0 & 0 & 0 & 0 & 0 & -\alpha & 1 & -\alpha \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ . \\ . \\ . \\ b_n \\ b_{n+1} \end{bmatrix} = \begin{bmatrix} M_0 \\ M_1 \\ M_2 \\ . \\ . \\ . \\ M_n \\ M_{n+1} \end{bmatrix}$$

It is understood here that $M_0 = 0$ and $M_{n+1} = \bar{b}_{n+1}$: these equations represent the exogenous market prices at the extremes.

The matrix has an interesting structure, and some properties can be derived from inverting it. For $n = 2$, the inverse is (setting $A_2 = 1 - \alpha^2 = \frac{21}{25}$):

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ \frac{\alpha}{A_2} & \frac{1}{A_2} & \frac{\alpha}{A_2} & \frac{\alpha^2}{A_2} \\ \frac{\alpha^2}{A_2} & \frac{\alpha}{A_2} & \frac{1}{A_2} & \frac{\alpha}{A_2} \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

Hence the solution is

$$\begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} M_0 \\ \frac{1}{1-\alpha^2}\left(M_1 + \alpha M_0 + \alpha M_2 + \alpha^2 M_3\right) \\ \frac{1}{1-\alpha^2}\left(M_2 + \alpha M_1 + \alpha M_3 + \alpha^2 M_0\right) \\ M_3 \end{bmatrix}$$

Interesting effects from the chain-linking of markets can be seen here. For instance, a reduction in M_3 (e.g., a reduction in costs specific to barges serving the lower market) reduces both b_2 and b_1, but it reduces b_2 by more than it reduces b_1 through the dampened knock-on effect.

For $n = 3$, we have the inverse as

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ \frac{\alpha-\alpha^3}{A_3} & \frac{1-\alpha^2}{A_3} & \frac{\alpha}{A_3} & \frac{\alpha^2}{A_3} & \frac{\alpha^3}{A_3} \\ \frac{\alpha^2}{A_3} & \frac{\alpha}{A_3} & \frac{1}{A_3} & \frac{\alpha}{A_3} & \frac{\alpha^2}{A_3} \\ \frac{\alpha^3}{A_3} & \frac{\alpha^2}{A_3} & \frac{\alpha}{A_3} & \frac{1-\alpha^2}{A_3} & \frac{\alpha-\alpha^3}{A_3} \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix},$$

with $A_3 = 1 - 2\alpha^2 = \frac{17}{25}$, and the solution is

$$\begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} M_0 \\ \frac{1}{1-2\alpha^2}\left(M_1 + \alpha M_0 + \alpha M_2 - \alpha^2 M_1 - \alpha^3 M_0 + \alpha^2 M_3 + \alpha^3 M_4\right) \\ \frac{1}{1-2\alpha^2}\left(M_2 + \alpha M_1 + \alpha M_3 + \alpha^2 M_0 + \alpha^2 M_4\right) \\ \frac{1}{1-2\alpha^2}\left(M_3 + \alpha M_2 + \alpha M_4 + \alpha^2 M_1 + \alpha^3 M_0 - \alpha^2 M_3 - \alpha^3 M_4\right) \\ M_4 \end{bmatrix}.$$

For higher values of n the matrix is still readily inverted, and the analogous solutions can can be derived. However, the basic structure of chain-linking can already be seen from the case $n = 3$. Indeed, it is apparent that a reduction in M_3 reduces all barge rates, again with a dampened effect further downstream. Note though that a lower M_1 has a symmetric effect. However, if the lower M_1 stems from lock improvements far downstream, this will reduce M_2 and M_3 too, so having a larger impact than a straight reduction in M_3. This means that improvements at the lowest levels, through which all upstream traffic passes, have a larger global impact.

To better see the structure of the problem, and to get further results, now consider the case $n = 4$:

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ -\alpha & 1 & -\alpha & 0 & 0 & 0 \\ 0 & -\alpha & 1 & -\alpha & 0 & 0 \\ 0 & 0 & -\alpha & 1 & -\alpha & 0 \\ 0 & 0 & 0 & -\alpha & 1 & -\alpha \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix} = \begin{bmatrix} M_0 \\ M_1 \\ M_2 \\ M_3 \\ M_4 \\ M_5 \end{bmatrix}$$

The inverse, setting $A_4 = 1 - 3\alpha^2 + \alpha^4$, is

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ \frac{\alpha-2\alpha^3}{A_4} & \frac{-2\alpha^2+1}{A_4} & \frac{\alpha-\alpha^3}{A_4} & \frac{\alpha^2}{A_4} & \frac{\alpha^3}{A_4} & \frac{\alpha^4}{A_4} \\ \frac{\alpha^2-\alpha^4}{A_4} & \frac{\alpha-\alpha^3}{A_4} & \frac{-\alpha^2+1}{A_4} & \frac{\alpha}{A_4} & \frac{\alpha^2}{A_4} & \frac{\alpha^3}{A_4} \\ \frac{\alpha^3}{A_4} & \frac{\alpha^2}{A_4} & \frac{\alpha}{A_4} & \frac{-\alpha^2+1}{A_4} & \frac{\alpha-\alpha^3}{A_4} & \frac{\alpha^2-\alpha^4}{A_4} \\ \frac{\alpha^4}{A_4} & \frac{\alpha^3}{A_4} & \frac{\alpha^2}{A_4} & \frac{\alpha-\alpha^3}{A_4} & \frac{-2\alpha^2+1}{A_4} & \frac{\alpha-2\alpha^3}{A_4} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix},$$

and hence we can find the solution for the vector of b's as

$$\begin{bmatrix} M_0 \\ \frac{\alpha^2}{A_4}M_3 + \frac{\alpha^3}{A_4}M_4 + \frac{\alpha^4}{A_4}M_5 + \frac{1}{A_4}M_0\left(\alpha - 2\alpha^3\right) + \frac{1}{A_4}M_2\left(\alpha-\alpha^3\right) + \frac{1}{A_4}M_1\left(-2\alpha^2+1\right) \\ \frac{\alpha}{A_4}M_3 + \frac{\alpha^2}{A_4}M_4 + \frac{\alpha^3}{A_4}M_5 + \frac{1}{A_4}M_1\left(\alpha-\alpha^3\right) + \frac{1}{A_4}M_2\left(-\alpha^2+1\right) + \frac{1}{A_4}M_0\left(\alpha^2-\alpha^4\right) \\ \frac{\alpha}{A_4}M_2 + \frac{\alpha^2}{A_4}M_1 + \frac{\alpha^3}{A_4}M_0 + \frac{1}{A_4}M_4\left(\alpha-\alpha^3\right) + \frac{1}{A_4}M_3\left(-\alpha^2+1\right) + \frac{1}{A_4}M_5\left(\alpha^2-\alpha^4\right) \\ \frac{\alpha^2}{A_4}M_2 + \frac{\alpha^3}{A_4}M_1 + \frac{\alpha^4}{A_4}M_0 + \frac{1}{A_4}M_3\left(\alpha-\alpha^3\right) + \frac{1}{A_4}M_5\left(\alpha-2\alpha^3\right) + \frac{1}{A_4}M_4\left(-2\alpha^2+1\right) \\ M_5 \end{bmatrix}$$

The most striking result from this is what happens when (for example) we raise M_3 and M_4 say by \$1: this would be like an increase in costs, due to deteriorating locks say, that is only incurred by the top 2 pools. Nonetheless, although only b_3 and b_4 are directly impacted, there is a domino effect down the line and back up again. The comparative statics are calculated as

$$\begin{bmatrix} db_0 \\ db_1 \\ db_2 \\ db_3 \\ db_4 \\ db_5 \end{bmatrix} = \begin{bmatrix} 0 \\ \frac{\alpha^2}{A_4} + \frac{\alpha^3}{A_4} \\ \frac{\alpha}{A_4} + \frac{\alpha^2}{A_4} \\ \frac{1}{A_4}\left(\alpha-\alpha^3\right) + \frac{1}{A_4}\left(-\alpha^2+1\right) \\ \frac{1}{A_4}\left(\alpha-\alpha^3\right) + \frac{1}{A_4}\left(-2\alpha^2+1\right) \\ 0 \end{bmatrix}.$$

Now let us calibrate these numbers using the model's parameter value $\alpha = 0.2$, so that $-3\left(0.2\right)^2 + 0.2^4 + 1 = 0.8816$. This yields

$$\begin{bmatrix} db_0 \\ db_1 \\ db_2 \\ db_3 \\ db_4 \\ db_5 \end{bmatrix} = \begin{bmatrix} 0 \\ 5.4 \times 10^{-2} \\ 0.27 \\ 1.30 \\ 1.26 \\ 0 \end{bmatrix}.$$

There is nearly no effect on the price from the farthest away pool, which is interesting insofar as the chain-link effect dampens quite quickly. However, the neighbor price (b_2) has quite a strong rise. The big impact though is on the prices in the top two pools that ship down the river. There the cost pass-on actually exceeds unity, and by quite a wide margin. Thus, in this system the cost pass-on in more than 100%, despite the fact that the demand structure is effectively linear.[17]

To view this result from the other perspective, suppose instead we envisaged a situation where the locks were improved and reduced costs to all those upstream of the improvements. Not only are shippers downstream better off, but those upstream are better off by an amount exceeding the actual reduction in costs per trip. That is, market power of barge operators here is diminished to such an extent that the social benefits through reduced prices is more than the cost savings

5 Conclusions

We have examined the consequences of market power in the transportation sector by means of two different set-ups that highlight first the competition between barge and rail, and, second, the case of barge and barge competition. In the first case, assuming equal market power in both sectors, the barge market tends to over-price the cost advantage which we ascribed to it, rendering the barge market too small in equilibrium. If, instead, the barge market is competitive while the rail market has the market power, the rail market will be overpriced (and the rail market too small).

The second case analyzed suppresses competition with rail and involves only competition between barge operators with market power. The demand structure emphasizes the chain-linking of markets, and points to the importance of lock improvements at the locks (downstream) through which many shipments will

[17] With linear demands, the monopoly pass-through is 50%. However, with a covered market (e.g. the classic Hotelling model), raising both costs the same amount causes perfect pass-through of 100%. The striking result here is that this benchmark is surpassed, even though the costs have risen for only two firms.

pass. A similar chain-linking arises under Cournot competition: Anderson and Wilson (2005) provide some comparison between this and the current Bertrand case.

Our work is motivated by the need to assess the benefits of investment in the waterway infrastructure. The models developed and employed by the policy-makers are underdeveloped, and this research along with our previous work is part of a process of improving these assessments. There is, however, considerable room for extensions. Specifically, the models are stylized and ought to be extended to consider two-way traffic, non-uniformities in production, discrete locations of shippers, and, in the long-run, endogenous locations for rail and river terminals.

Another important extension would be to allow for congestion not only at the nodes (i.e., the locks), but also along the links (i.e., the rivers). The bottleneck model of Arnott, de Palma, and Lindsey (1990, 1993) provides useful modeling background in this regard. Such extensions are centrally important to empirically implement the model and to evaluate alternative investment strategies such as investment in the node (e.g., increasing the capacity of the locks) versus investment in the links (e.g., deepening the channels). In addition, for welfare analyses, there are considerable differences in the emissions by mode, and the models can be adapted to reflect these differences en route to policy measures that affect modal splits.

6 References

Anderson, S. P., 2005. Product Differentiation. New Palgrave Dictionary, Second Edition.

Anderson, S. P., de Palma, A., 2001. Product Diversity in Asymmetric Oligopoly: is the Quality of Consumer Goods too Low? Journal of Industrial

Economics. 49, 113-135.

Anderson, S. P., de Palma, A., Thisse, J. F., 1992. Discrete choice theory of product differentiation. MIT press.

Anderson, S. P., Wilson, W. W., 2004. Spatial Modeling in Transportation: Congestion and Mode Choice. Institute for Water Resources Report 04-NETS-P-06. Available at www.CORPSNETS.US

Anderson, S. P., and Wilson, W. W., 2005. Market Power in Transportation: Spatial Equilibrium and Welfare under Cournot Competition. Institute for Water Resources Report 05-NETS-P-04. Available at www.CORPSNETS.US. Available at www.CORPSNETS.US.

Anderson, S. P., Wilson, W. W., 2007. Spatial Modeling in Transportation: Infrastructure, Planning and Welfare, in: Plant, J. (Ed.) in Jeremy Plant ed., Handbook of Transportation Policy and Administration . CRC Press, Middletown, PA. pp. 255-280.

Anderson, S. P., Wilson, W. W., 2008. Spatial Competition, Pricing, and Market Power in Transportation: A Dominant Firm Model. Journal of Regional Science. 48, 367-397.

Archibald, G. C., Eaton, B. C., Lipsey, R. G., 1986 Address Models of Value Theory. In: Stiglitz, J. E., Mathewson, F. G. (Eds.), New Developments in the Analysis of Market Structure. Cambridge: MIT Press, pp. 3-47.

Arnott, R., de Palma, A. and Lindsey, R. 1990. Economics of a bottleneck. Journal of Urban Economics, 27, 111-130

Arnott, R., de Palma, A. and Lindsey, R. 1993. A Structural Model of Peak-Period Congestion: A Traffic Bottleneck with Elastic Demand. American Economic Review,

83, 161-179.

Berry, S., Hewings, G., Leven, C., 2000. Adequacy of research on upper Mississippi-Illinois river navigation project. Northwest-Midwest Institute.

Böckem, Sabine, 1994. A Generalized Model of Horizontal Product Differentiation. Journal of Industrial Economics, 42, 287-298.

Boyer, K. D., Wilson, W. W. 2005. Estimation of Demands at the Pool Level. Institute for Water Resources Report 05-NETS-R-03. Available at www.corpsnets.us

Enke, S., 1951. Equilibrium among spatially separated markets: solution by electric analogue. Econometrica, 19, 40-47.

Gabszewicz, J. J., Thisse, J. F., 1992. Location. In: Aumann, R. J., Hart, S. (Eds.), Handbook of game theory with economic applications, Volume 2. Elsevier.

Hotelling, H., 1929. Stability in Competition. Economic Journal, 39, 41-57.

McDonald, J. M., 1987. Competition and Rail Rates for the Shipment of Corn, Soybeans, and Wheat. RAND Journal of Economics, 18, 151-163.

Phlips, L., 1983. The Economics of Price Discrimination. Cambridge University Press.

Samuelson, P. A., 1952. Spatial Price Equilibrium and Linear Programming. American Economic Review, 42, 283-303.

Takayama, T., Judge, G. G., 1964. Equilibrium among spatially separated markets: a reformulation. Econometrica, 32, 510-524.

Train, K., Wilson, W. W., 2004. Shipper Responses to Changes in Transportation Rates and Times: The Mid-American Grain Study. Institute for Water Resources, Army Corps of Engineers Report No. 04-NETS-R-02. Available at www.CORPSNETS.US

Train, K., Wilson, W. W., 2008a. Transportation Demand and Volume Sensitivity: A Study of Grain Shippers in the Upper Mississippi River Valley. Transportation Research Record. 2062, 66-73.

Train, K., Wilson, W. W., 2008b. Estimation on Stated-Preference Experiments Constructed from Revealed-Preference Choices. Transportation Research

- Part B. 42, 191-2003

Vachal, Kim, Hough, Jill, and Griffin, Gene, (2005). U.S. Waterways: A Barge Sector Industrial Organization Analysis. Navigation and Economic Technologies Report, Institute for Water Resources, Army Corps of Engineers. Available at http://www.corpsnets.us/docs/IndOrgStudyInlandWaterways/BargeSectorIndusOrg.pdf

Wilson, W. W. 1996. Legislated Market Dominance. Research in Transportation Economics. 4, 33-48.

Wilson, W. W 2006. Vessel, Firm, and Lock Efficiency Measures in Lock Performance. Transportation Research Record: Journal of the Transportation

Research Board No. 1963, 1-8.

7 Appendix

INSERT HERE: Map of US waterways