December 1, 2005

NETS

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MARKET POWER IN TRANSPORTATION

Spatial Equilibrium and Welfare under Bertrand Competition

US Army Corps of Engineers®

IWR Report 05-NETS-P-07

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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Market Power in Transportation: Spatial Equilibrium and Welfare under Bertrand Competition *

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Abstract

We develop spatial competition a la Bertrand for barge shipping along a waterway. Equilibrium prices are derived for two variations. For each case, we first give the perfectly competitive benchmark (when all modes are priced at marginal cost) before introducing market power on the modes. The paper emphasizes strategic rivalry (and market power) in two dimensions, and, for tractability, we consider each in isolation from the other. This gives rise to two variants of the base model. First, we analyze oligopolistic rivalry between barge operators and rail operators. The analysis indicates various inefficiencies stemming from market power. In particular, the advantage that each transport mode has over some shippers gives it market power and so prices are not driven to marginal cost. More subtly, transporters' equilibrium prices will tend to be overprice cost advantages (i.e., price differences will be too small in equilibrium). In the second variant, we address rivalry among barge operators shipping from neighboring river terminals. Here, basic shipping costs increase with distance from the final market in a natural fashion in this setting. The model introduces demand elasticity in a novel fashion into a standard spatial approach by treating as fixed the shipping costs at the extremes of the market (this corresponds to shippers trucking directly to the market if they are close enough to the final market, and shipping to an alternative final market if they are far enough away). We thus derive the equilibrium for a "chain-linked" market system to show that operators with cost advantages parlay these into market size advantages. Welfare implications from transportation improvements are drawn. We break down the surplus changes accruing to different parties in order to indicate gainers, losers, and overall benefits.

KEYWORDS: Market power, shipping price competition, spatial equilibrium, transportation networks

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1 Introduction

The objective of the paper is to look at market power implications in transportation markets. The setting explicitly recognizes spatial heterogeneity of suppliers and demanders of transportation services. The suppliers of transportation services offer rates from different locations to the final market. The demanders (or shippers) also are located at different points in space and so have heterogeneous preferences across suppliers: ceteris paribus, a closer supplier is prefered. This latter feature imbues the suppliers with market power over those shippers located close by.

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 (2004b). 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 general, when there is market power in the barge sector, there are two dimensions to analyze in the implementation of this market power. These are the rivalry with other transport modes, and the rivalry among operators in the same mode. In order to understand how these different types of rivalry play out, and also for reasons of clarity and tractability, we address them separately in stylized model variants.

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) will be priced cheaper 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 will actually be under-utilized in equilibrium.[1]

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 and chain-linked.[2]

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

In the benchmark model, 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

[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 (2005a).

river terminals at latitudes y_i, $i = 1, ..., n$, indexed so that a higher value of y_i indicates a location further North. The cost of shipping a unit of the commodity from location y_i by river (i.e., by barge) all the way to the final transshipment point is $\bar{b}_i$. 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.[3]

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 location 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 longitude as the river terminal).[4] 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 will 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 in this Section.[5] 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 boundary and allows it only between rail and barge within a given band (or stripe) of latitudes.[6]

[3] 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.

[4] 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.

[5] This is the focus of the next Section.

[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 com-

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 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]

The basic economic geography is illustrated in Figure 1. The Figure 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 $x = \delta$).

INSERT FIGURE 1. Economic Geography for Barge-Rail Competition

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

petitive 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 Wlison, 2005a, 2005b).

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 y_i or r_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) 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).[8] 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.,

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

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

[8] 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 propery follows from the block metric for transportation.

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 high truck rates imply that distance is costly to overcome.

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.

The basic market power analysis is based on an asymmetric version of Hotelling's (1929) model.[9] 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). The situation is illustrated in Figure 2.[10] 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 large market for barge than rail.

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

[9] Hotelling's simple framework remains an enduring one that has attracted many researchers. A forthcoming conference in CORE in Belgium is addressed solely to developments following Hotelling's (1929) paper on "Stability in competition." 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), and Gabszewicz and Thisse (1987).

[10] The same basic picture applies to the competitive case, with $\bar{r}_i$ and $\bar{b}_i$ replacing r_i and b_i.

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:

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

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:

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

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 $(\delta - \hat{x}_i) = \frac{(r_i - \bar{r}_i)}{2t}$.[11] These are respectively rewritten as

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

and

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

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 (7a) and (8) above as:[12]

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

in equilibrium.[13] Note that the market splits at the mid-point under symmetry of fundamental costs. Note too that the solution is independent of monetary 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 $b_i = t\left(\delta + \frac{\bar{r}_i - \bar{b}_i}{3t}\right) + \bar{b}_i = t\delta + \frac{1}{3}\left(\bar{r}_i + 2\bar{b}_i\right)$. This means that there are 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

[11] These together yield the intriguing property that that the sum of the mark-ups is proportional to the monetary distance between the alternatives; namely, $\left(b_i - \bar{b}_i\right) + \left(r_i - \bar{r}_i\right) = 2t\delta$.

[12] 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.

[13] 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 $\bar{r}_i \geq \bar{b}_i + 3t\delta$.

much market to its rivval. 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, $r_i = 2t\left(\delta - \frac{\delta}{2} - \frac{\bar{r}_i - \bar{b}_i}{6t}\right) + \bar{r}_i = 2t\delta + \frac{2\bar{r}_i + \bar{b}_i}{3}$. 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).[14] To see this, note that the socially optimal allocation involves both modes priced at cost, leading to an optimal allocation of

$$\hat{x}_i^o = \frac{\delta}{2} + \frac{\bar{r}_i - \bar{b}_i}{2t}. \tag{10}$$

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

[14] 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.

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.[15] 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). 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

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

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.

4 Barge-barge competition

Assume now that the railroad has been closed down (or never existed), and so the competition is between barge operators in adjacent pools only. Assume again that the shippers are located with uniform density over a region of width δ contiguous to the river.[16] 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 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

[16] More complex versions of the model would have reservation prices that would bind for some shippers, etc.

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

$$\bar{b}_{i-1} + t\left[\bar{y}_i - y_{i-1}\right] = \bar{b}_i + t\left[y_i - \bar{y}_i\right], \qquad i = 1, ..., n \tag{11}$$

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

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

We assume that the lowest market (the one farthest to the South) is determined by simply trucking to the final market. This is equivalent to setting $b_0 = 0$ (so there is no market power held over shippers in this 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), $b_0 = 0$ 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[17]:

$$\pi_{bi} = \left(b_i - \bar{b}_i\right)\left(\hat{y}_{i+1} - \hat{y}_i\right) \tag{12}$$

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

$$\frac{\partial \pi_{bi}}{\partial b_i} = \left(\hat{y}_{i+1} - \hat{y}_i\right) - \frac{\left(b_i - \bar{b}_i\right)}{4t} = 0. \tag{13}$$

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,

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

[17] 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.

Denote the Left-Hand-Side $M_i = \frac{2t(y_{i+1}-y_{i-1})+\bar{b}_i}{5}$, $i = 1,...n$, and set $\alpha = \frac{2}{5}$. 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

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

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.

Some properties can be derived from inverting the matrix. For $n = 2$, the inverse is (setting $A = \alpha^2 - 1$):

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ -\frac{a}{A} & -\frac{1}{A} & -\frac{a}{A} & -\frac{a^2}{A} \\ -\frac{a^2}{A} & -\frac{a}{A} & -\frac{1}{A} & -\frac{a}{A} \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

Hence the solution is

$$\begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} M_0 \\ \frac{1}{a^2-1}\left(-M_1 - aM_0 - aM_2 - a^2M_3\right) \\ \frac{1}{a^2-1}\left(-M_2 - aM_1 - aM_3 - a^2M_0\right) \\ M_3 \end{bmatrix}$$

Interesting effects from the chain-linking of markets can be seen here. For instance, a reduction in M_3 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

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ \frac{-a+a^3}{A} & \frac{a^2-1}{A} & -\frac{a}{A} & -\frac{a^2}{A} & -\frac{a^3}{A} \\ -\frac{a^2}{A} & -\frac{a}{A} & -\frac{1}{A} & -\frac{a}{A} & -\frac{a^2}{A} \\ -\frac{a^3}{A} & -\frac{a^2}{A} & -\frac{a}{A} & \frac{a^2-1}{A} & \frac{-a+a^3}{A} \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix},$$

with $A = 2a^2 - 1$, and the solution is

$$\begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} M_0 \\ \frac{1}{2a^2-1}\left(-M_1 - aM_0 - aM_2 + a^2M_1 + a^3M_0 - a^2M_3 - a^3M_4\right) \\ \frac{1}{2a^2-1}\left(-M_2 - aM_1 - aM_3 - a^2M_0 - a^2M_4\right) \\ \frac{1}{2a^2-1}\left(-M_3 - aM_2 - aM_4 - a^2M_1 - a^3M_0 + a^2M_3 + a^3M_4\right) \\ M_4 \end{bmatrix}.$$

Here 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.

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 have 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 full analysis of this case remains to be undertaken. It would involve the barge rates being effectively fixed at $\bar{b}_i$, $i = 1, ..., n$, while the railroad sets the rates r_i.as a monopolist.

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 pass. This analysis could usefully be extended in future work to include congestion.

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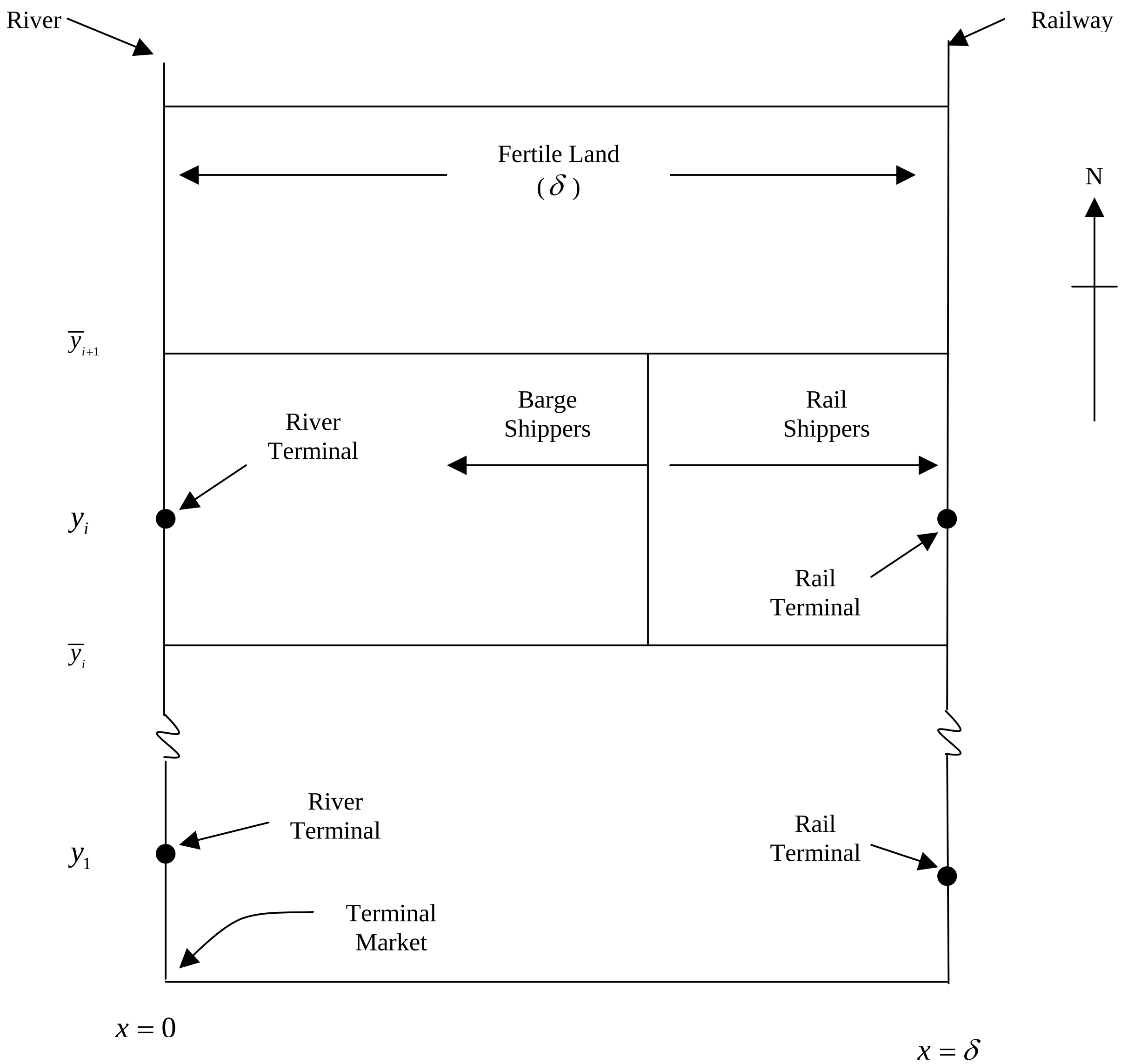

Figure 1.--Economic Geography for Barge-Rail Competition

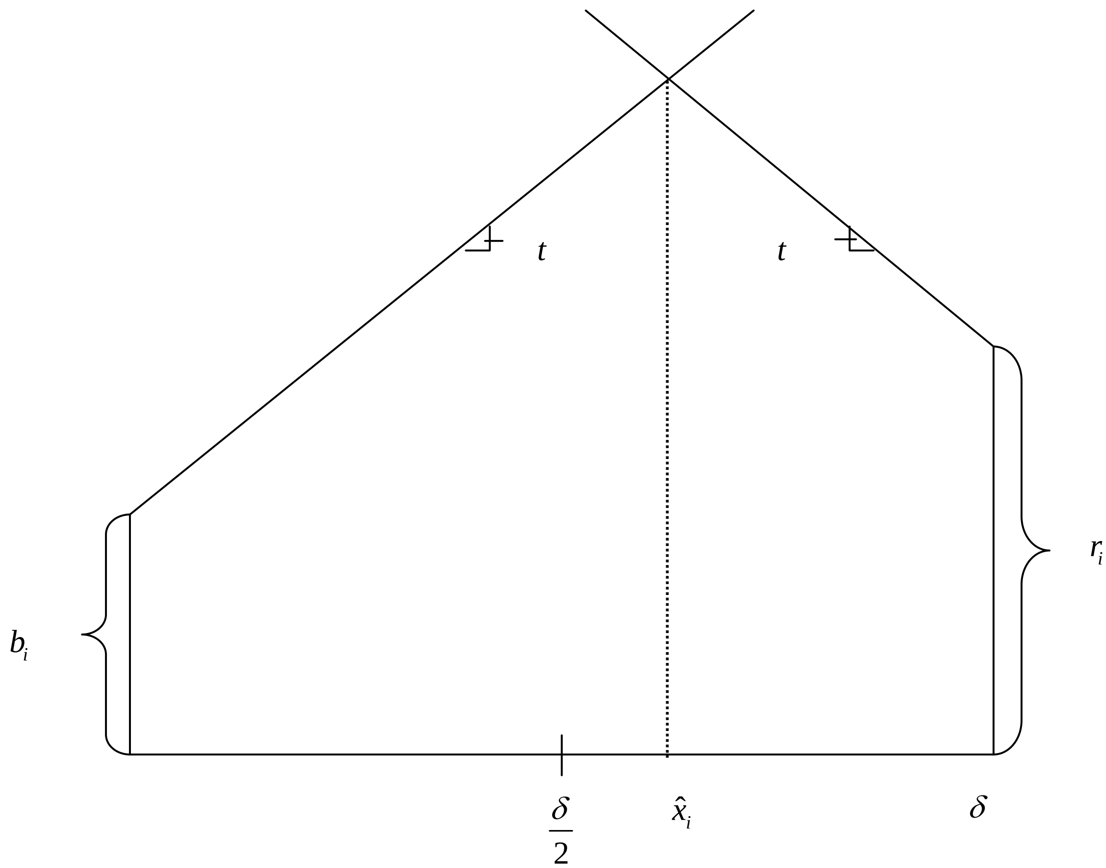

Figure 2.--Barge-Rail Market Division (longitudinal split).

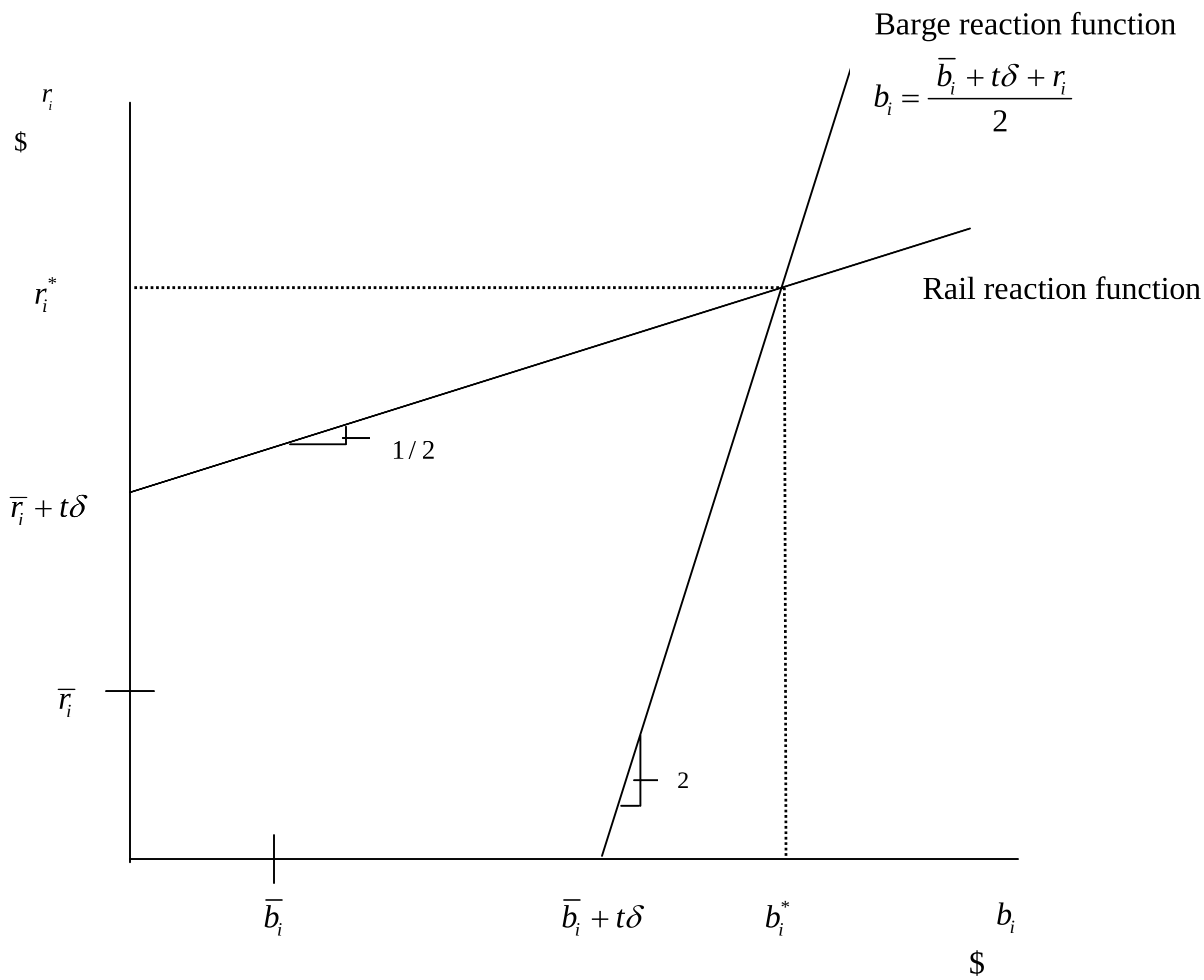

Figure 3.--Reaction Functions and Equilibrium for Barge-Rail Formulation

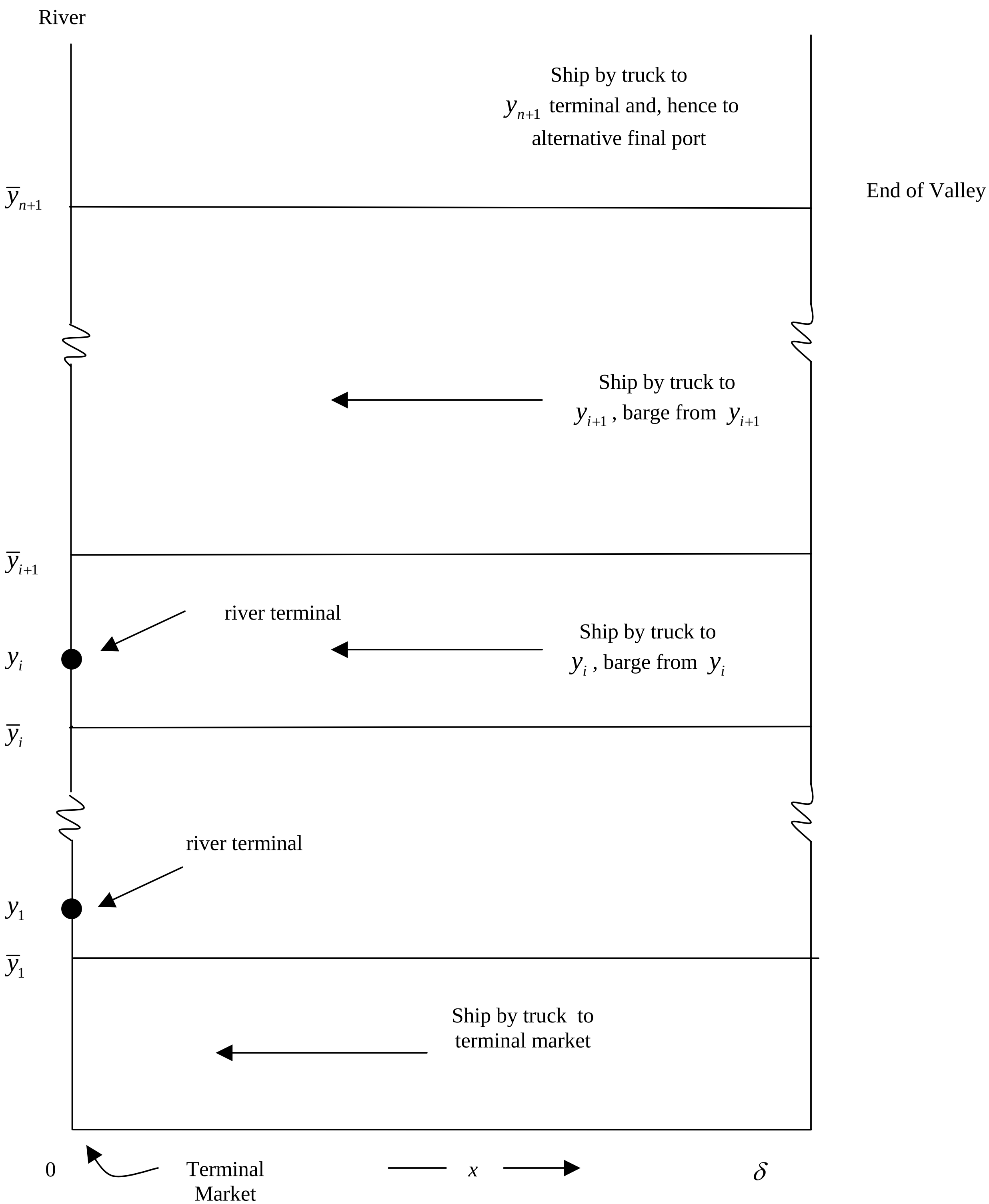

Figure 4.--Economic Geography for Barge-Barge Model

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- 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.

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