The Economic Foundations of the Ohio River Navigation Investment Model (ORNIM)

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Abstract

The Ohio River Navigation Investment Model (ORNIM), built by Oak Ridge National Laboratory in collaboration with the Army Corps of Engineers, estimates the benefits of navigation improvements and balances those benefits against the costs of those improvements. This paper identifies the economic assumptions within ORNIM, provides the rational for these assumptions, and addresses how these assumptions alter the estimates of inland-water navigation benefits, as compared to the theoretical model. ORNIM is a spatially-detailed partial-equilibrium model, which incorporates the following assumptions: (1) demand for individual movements, provided exogenously, is perfectly inelastic; (2) willingness-to-pay for individual river movements is equal to the exogenously given least-cost alternative rail rate; and (3) supply of rail for individual movements is perfectly elastic at the exogenously given rail rate. The first assumption biases upward estimates of with-project benefits. However, empirical evidence on demand elasticity and willingness-to-pay suggests that these assumptions are reasonable in the short-run. In the long-run, decisions to move cargo by water depend only in part on river rates, with environmental and energy policies also being critical. Appropriately, the demand for waterway movements is exogenous to ORNIM; and the Corps' recent scenario-based demand approach is applauded. The third assumption unequivocally biases downward ORNIM's estimate of with-project benefits. Other assumptions also bias benefits downward. Future ORNIM enhancements include improvements in the analysis of congestion fees, environmental externalities, traffic management, and system reliability. Improvements in data quantity and quality also are needed. ORNIM, like other navigation models, is data constrained. Without significant data improvements, attempts to relax economic assumptions within ORNIM are of questionable value.

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INTRODUCTION AND OVERVIEW

This paper provides the economic foundations of the Ohio River Navigation Investment Model (ORNIM). More specifically, it identifies the economic assumptions made within ORNIM, provides the rationale for these assumptions, and addresses how these assumptions may alter the estimates of inland-waterway navigation benefits and costs as compared to the theoretical ideal. The paper also discusses how ORNIM and the overall exercise of modeling inland navigation investments could be improved with additional resources for analysis. A clear understanding of the economic foundations on which ORNIM is built allows the potential benefits of future theoretical and empirical work to be evaluated from the perspective of providing the most accurate and useful information to decision makers.

ORNIM was built by Oak Ridge National Laboratory (ORNL) in collaboration with the Navigation Planning Center of the Great Lakes and Ohio River Division (LRD) of the U.S. Army Corps of Engineers (Corps). The purpose of ORNIM is to estimate the benefits of improvements to the navigation infrastructure of the Ohio River System – e.g., extended or new locks, channel improvements, replacement of key lock and dam components, alternative maintenance policies, etc. -- and to balance those benefits against the estimated costs of those improvements. By doing so, ORNIM can suggest the optimal set of infrastructure investments over time.

ORNIM is based on a long history of model development within the Corps. The Tow Cost Model (TCM) and the Equilibrium Model (EQ), which had their beginnings in the 1970s, served as a starting point for ORNIM [*1*]. ORNIM takes advantage of additional and more refined data, in combination with state-of-the-art computer software, hardware, and computational algorithms, to move to a new frontier of navigation modeling. ORNIM allows users to do analyses not possible with earlier generation models, e.g. optimal selection and timing of a large number of potential river system improvements. State-of-the-art hardware, software, and solution algorithms also allow analysts to run numerous what-if cases in a fraction of the time required to run a single case with previous generation models.

This paper moves toward its primary objective -- i.e., identifying how economic assumptions within ORNIM may bias the estimate of benefits as compared to the theoretical model -- by mapping the movement from what economic theory suggests, to the economic assumptions adopted within ORNIM. In the extreme, and in the absence of limitations on data availability and computation resources, a spatially-detailed general equilibrium model could be constructed. We argue that a model at this extreme is not required to measure the benefits of "without and with-project conditions." A spatially-detailed partial-equilibrium model, which ORMIM is, adequately addresses the benefits of what are relatively small changes to the transportation network. Further, the simplifying economic assumptions adopted within ORNIM are consistent with data availability and the Corps' desire to be conservative in estimating the benefits of improvements to the Ohio River System (See [*2*] for a more detailed discussion.).

ORNIM

The ORNIM System is composed of three modules – the Lock Risk Module (LRM), the Waterway Supply and Demand Module (WSDM), and the Optimal Investment Module (Optimization). (See [*2*] and Figure 1 for more details.) LRM takes engineering inputs -- e.g., reliability estimates, component hazard functions, and repair protocols – to determine the probabilities of unplanned closures for each lock for each year. WSDM utilizes detailed information about the Ohio River network (a total of 56 locks with details about river sectors and nodes), towboat/barge operations (numerous tow types and barge configurations with different costs), lock operations, and cargo forecasts (nine commodities with some 31,000 potential movements per year) to estimate the annual equilibrium traffic. Optimization, which can be budget constrained, identifies the optimal set of investment options (e.g., construction, rehabs, and maintenance) at each lock for as much as a 70-year horizon. ORNIM's major economic assumptions are embedded within WSDM. (The benefits of navigation improvements are driven in large part by relieving delays caused by congestion. Estimates of delay are exogenous to ORNIM and are provided by the Waterway Analysis Model (WAM) [*3*].)

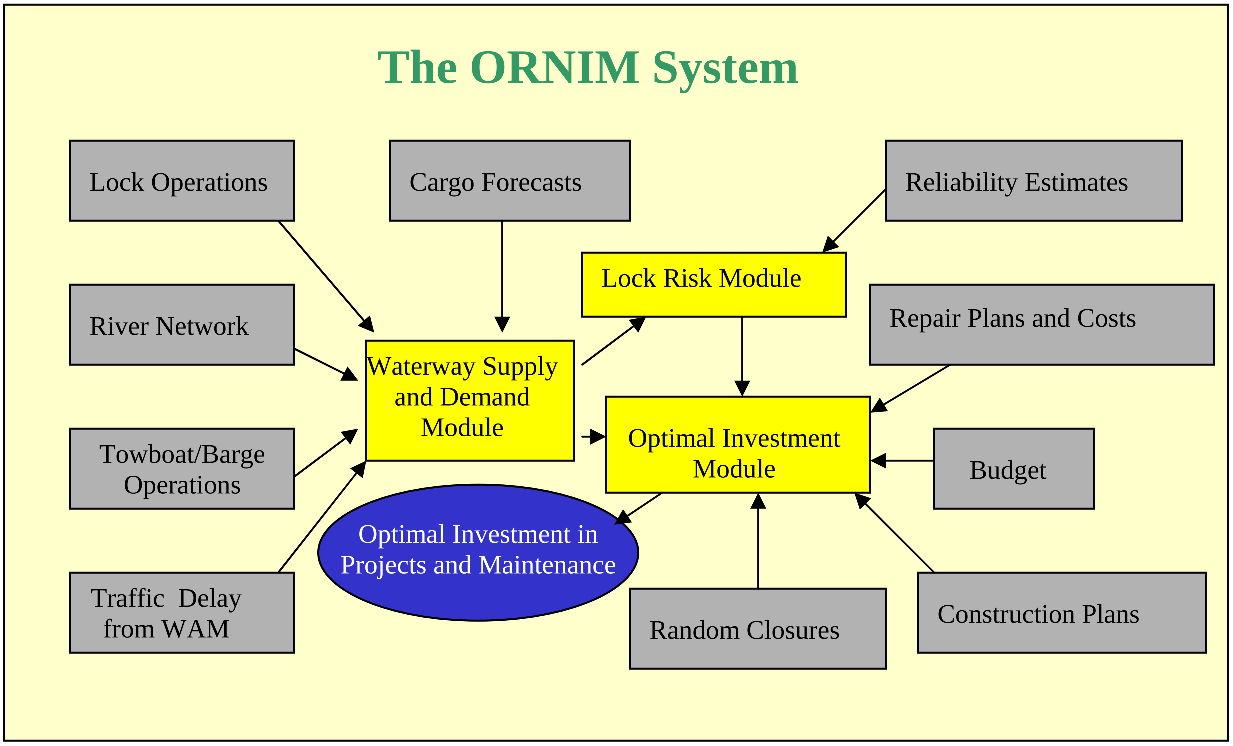

FIGURE 1 The ORNIM System

PRINCIPLES AND GUIDELINES

The Corps, and therefore ORNIM, must follow and be consistent with established Principles and Guidelines when estimating the benefits of river system improvements. Economic Principles and Guidelines (P&G), which were published in March 1983, lay out procedures for estimating National Economic Development (NED) benefits of inland navigation improvements [*4*]. These are based on (1) “the cost reduction of using the waterway by traffic that uses the waterway in the without-project condition;” (2) a shift-of-mode benefit for “traffic that would use a waterway with the project but uses a different mode, including a different waterway, without the project;” (3) a shift-of-origin benefit which “would result in a shift in the origin of a commodity;” (4) a new movement benefit “applies if a commodity or additional quantities of a commodity would be transported only because of lowered transportation charge with the Project;” and (5) the “use of rates for benefit measurement,” which basically acknowledges that an improved navigation system may induce a price decrease in the alternative of rail. However, P&G acknowledges that it is difficult to compute this effect and states that “rates (for rail or another alternative) will be used to measure shift of mode benefits.” (pages 49-50).

The P&G provides general guidance for doing benefits assessments, but do not overly restrict or dictate how the assessments should be done. P&G leaves open opportunities for analysts to improve their tools and assessments as new data become available and computational capabilities improve. ORNIM is a reflection of the Corps’ recognition that a new state-of-the-art is possible.

THE MODELING CONTINUUM: THE RANGE OF MODELS AND ECONOMIC THEORY

As with any empirical model, simplifying assumptions are made within ORNIM because of data, time, computational, and resource limitations. The keys in making simplifying assumptions are to clearly understand (1) the theoretical model that serves as a starting point for the analysis, (2) how the simplifying assumptions deviate from the theoretical model, (3) the reasonableness of the assumptions as compared to what we know about realworld markets, and (4) the implications of the assumptions in terms of biasing and/or reducing the accuracy of the model's results – in this case the estimation of with-project benefits. Empirical modeling requires a movement from the theoretical model to an empirical model that appropriately addresses the empirical question at hand and does so in a way that provides the most useful insights for decision-making, given the resource constraints placed on the overall analysis.

Economic models vary in terms of sectorial, spatial, and temporal detail. At one extreme are spatially-detailed computable general equilibrium models (CGE). CGE models are appropriate for issues expected to have economy-wide effects or whose economic effects follow complex but tractable pathways. If economy-wide effects are not realistically associated with the project being considered, modelers must make informed tradeoffs among the three dimensions. In the case of most river infrastructures, and especially in the case of the Ohio River System, ORNIM is designed to measure the benefits of relatively small infrastructure improvements – e.g., the extension of one or more locks, the rehab of specific parts at locks, the adoption of new approaches to maintain and repair locks (e.g., gate lifters). ORNIM is not designed to estimate the total benefits of the Ohio River System or the benefits the nation would lose if the Ohio River System no longer existed. A different kind of modeling approach and system would be required to estimate the total benefits of the Ohio River System.

Given ORNIM's objective, a spatially-detailed, partial-equilibrium model is sufficient. The alternatives being considered for the Ohio River System, even system-wide improvements, are relatively small modifications to the system. Also, alternatives that may be adopted for implementation, especially system-wide improvements, will require long periods of time for construction.

In the following section we review the economic foundations of spatially-detailed partial-equilibrium models, given perfect competition and no market failures. We discuss how with-project benefits should be measured within this modeling environment – i.e., as a gain in producer and consumer surplus. In later sections, we impose assumptions adopted within ORNIM and examine the implications of those assumptions in terms of biasing or otherwise impacting the estimate of with-project benefits.

CONCEPTUAL SPATIALLY DETAILED PARTIAL EQUILIBRIUM MODELS

Freight transportation exhibits a number of distinctive features that distinguishes it from other goods and services [*5, 6, 7*]. Some of these features include:

- It has derived demand resulting from the need to move commodities over geographical space.
- Its supply requires a combination of private and public inputs. Therefore, it exhibits congestible good attributes.
- It is part of a linked decision process by multiple economic agents, including producers, consumers, shippers/carriers and infrastructure managers, with spatial and time dimensions.

A reasonably complete representation of freight transportation should capture these features. Although all aspects of freight transportation are intrinsically linked, we illustrate the theoretical derivation of water transportation demand and supply from the viewpoint of the shipper/carrier. In doing this we abstract from the economics of waterway infrastructure management. In addition, we focus, first of all, on the short-run and then comment on long-run behavior.

Derived Demand for Freight Transportation

Assume we have two spatially separated competitive markets for a single commodity. The two markets, under no-trade equilibrium, are distinguished by the existence of a price premium in the first market above the price level in the other market. Refer to the first market as the "buyer" market, and the second market as the "supplier" market. We also assume a competitive transport market consisting of two alternative modes of commodity transportation between the two markets, i.e., water and rail. This can be viewed as two competing shipping agents or as two shipping modes that a single agent can use. For exposition purposes, we adopt the former.

Demand and supply functions can be derived for the two competitive markets under certain regularity conditions. Denoting these by D_s and S_s for the supplier market, and by D_b and S_b for the buyer market, excess demand or supply functions in these markets are given at each price level by:

$\mathrm{ED}_b = D_b - S_b$ (Excess demand in the buyer market)

and

$\mathrm{ES}_s = S_s - D_s$ (Excess supply in the supplier market)

Let P_s and P_b represent the price levels that we would obtain, without trade, in the supplier and buyer markets, respectively. Positive quantities at price levels above P_s on the excess supply curve represent what would be available in the supplier market, and positive quantities at price levels below P_b on the excess demand curve represent what would be demanded in the buyer market. These are illustrated in Figure 2. Existence of these positive quantities in *both* markets motivates trade and transportation between the two markets. The freight transportation demand curve between the two markets is constructed by plotting the price difference between the excess demand and supply curves for each shipment size. The maximum potential shipment occurs where the two excess curves cross, and corresponds to costless transportation between the two markets.

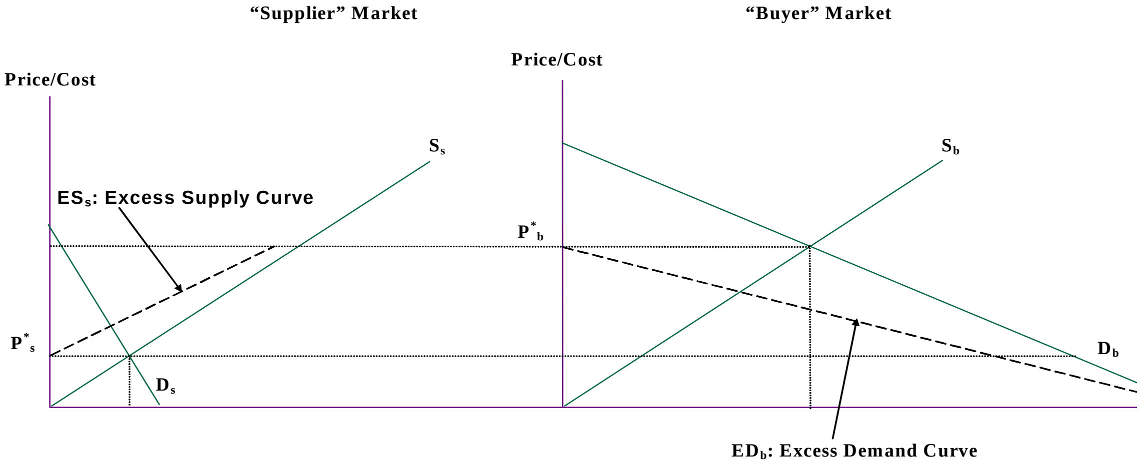

FIGURE 2 Derivation of Excess Demand and Supply Curves

Supply of Freight Transportation

Shipping agents engage in a profit maximizing, competitive process that serves to equilibrate the two markets, and determine the total shipment size and split between the two transportation modes. The cost function for each shipping agent can be written as:

$C_r = f(P_{h,r}, P_{u,r}, X_r; T_r, K_r)$ Rail

and

$C_w = f(P_{h,w}, P_{u,w}, X_w; T_w, K_w)$ Water

where $P_{h,w}$ and $P_{h,r}$ are vectors of waterway and railway handling/operating input prices, including labor, materials and energy; $P_{u,w}$ and $P_{u,r}$ are the per unit waterway and railway infrastructure user charge; K_w and K_r are the capital stock of waterway and railway shipping agents; Q_w and Q_r are shipment size by water and rail, and T_w and T_r are expected water and rail transportation time between the two markets. Note that under perfect information we assume that each shipping agent forms rational (correct) expectations of delay that do not vary with shipment size.

Marginal cost functions of shipment for the two modes are given as:

$$\frac{\partial C_w}{\partial Q_w} = MC_w \qquad \text{and} \qquad \frac{\partial C_r}{\partial Q_r} = MC_r$$

Points on the marginal cost functions, above the average variable cost, generate the supply curves for rail, S_r, and water, S_w, respectively. The transportation supply curve for commodity shipments between the two markets, S_q, is the horizontal sum of the supply curves for the two modes.

Derived Demand for Water Transportation

Total shipment between the two markets is the equilibrium point between the transportation demand and supply curves derived above. This solution, and the split between the two modes, can be equivalently illustrated by vertically adding the transportation supply curve, S_q, to the excess supply curve, ES_s. The resulting "full" excess supply curve, FS_q, can be used directly with the excess demand curve, ED_b, to derive the equilibrium shipment size between the two markets, identified as Q_{trade} in Figure 3. The split between the two transportation modes occurs where their marginal costs are equal to the marginal composite cost, i.e.

$MC_q = MC_r = MC_w$

This derivation is illustrated in Figure 3. Derived demand for water transportation is Q_w or the net of total shipment size, Q_{trade}, and the rail shipment size, Q_r. Thus, the demand (and demand function) for each transportation mode, even in this simple case, depends both on its own supply function and those of other modes. The incremental benefit of adding the waterway system to an existing railway system is measured by the shaded area in Figure 3.

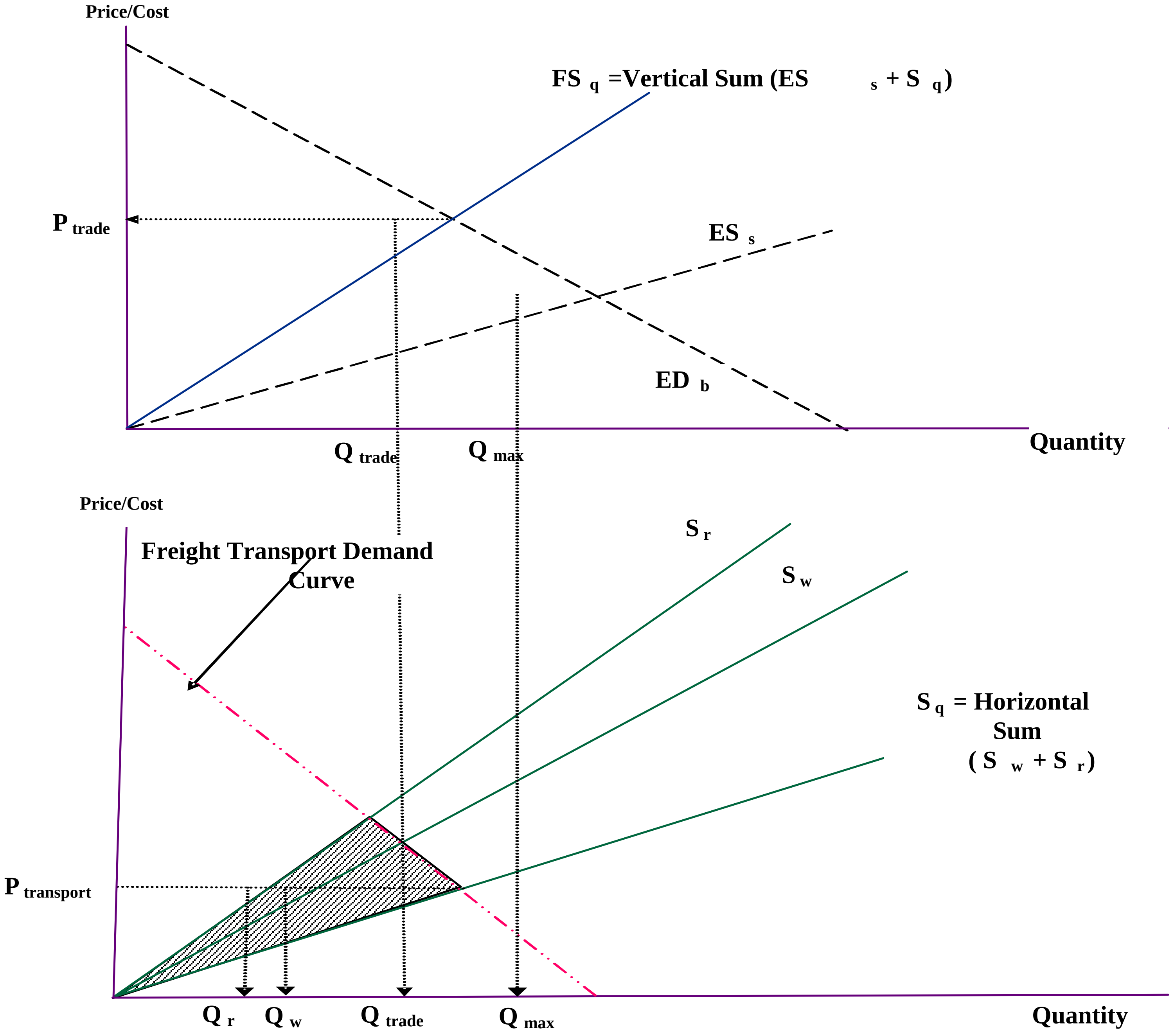

FIGURE 3 Derived Demand and Supply of Freight Transport

Extensions to the 2x2 Case

The foregoing discussion can be described as a 2x2 case, i.e., two markets and two transportation modes. In reality, we would be dealing with several commodities, with multiple buyer and supplier markets or sources, and multiple transportation modes or routes, for each commodity. Even in the presence of these complexities, the short-run transportation market may be adequately represented by the 2x2 case for each commodity and origin-destination combination. This is because the decision to trade a commodity between two locations is often made in advance of the actual transportation of the commodity. In the long run, however, every aspect of the transportation market adjusts. As a result, we would expect shifts in both excess demand and supply curves, adjustment of capital inputs, and exit/entry decisions by agents in all relevant markets. In addition, unlike the short-run, infrastructure economics must be considered in the long-run. The net effect of these long-run changes on the transportation market in general, and on individual transportation modes in particular is uncertain, and is an empirical issue.

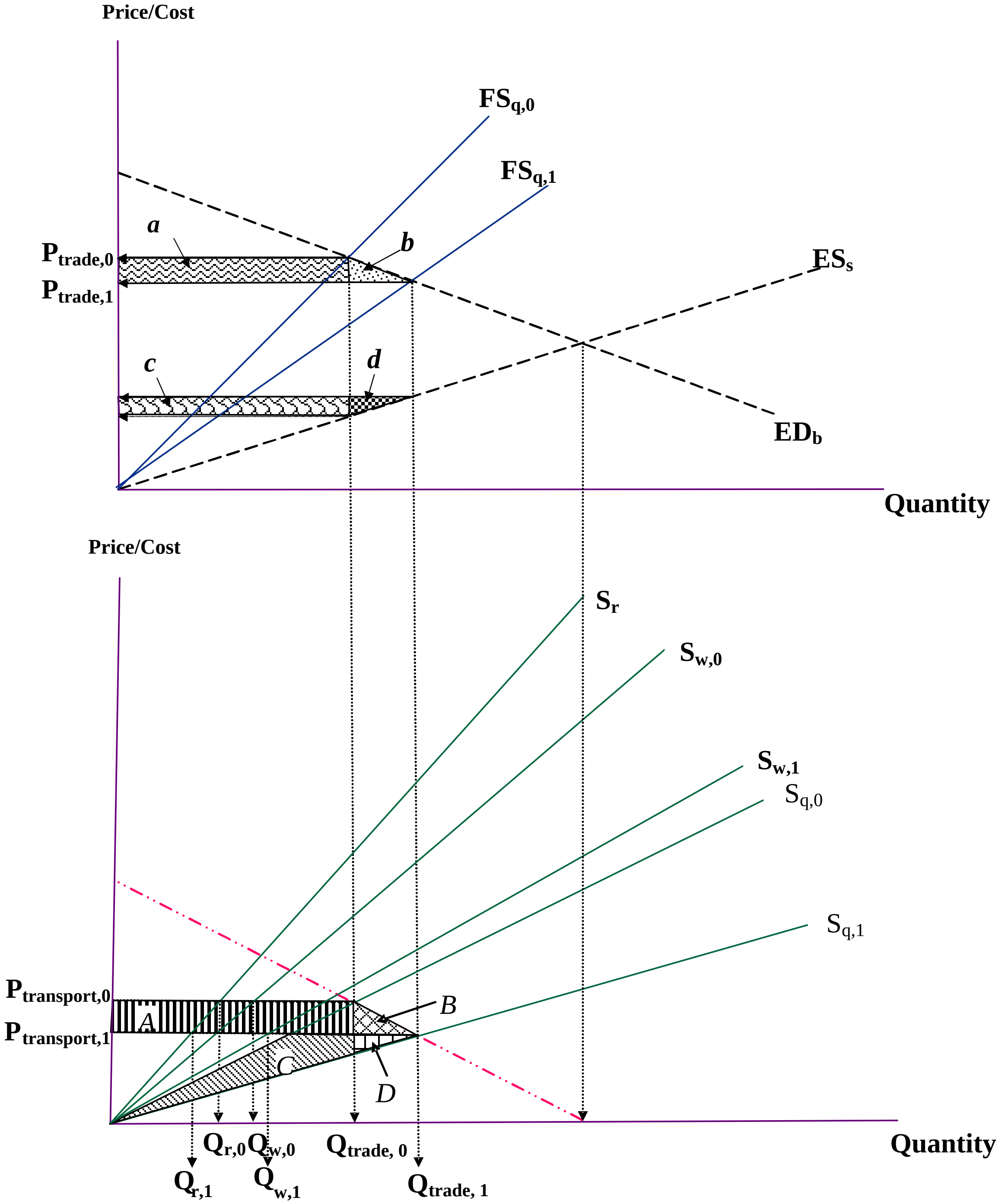

FIGURE 4 Benefits of Waterway Improvement Projects

MEASURING WITH-PROJECT BENEFITS

The primary effect of improvements to waterway infrastructure is to shift the marginal cost or supply curve for waterway transportation, S_w, downwards. In order to keep the illustration of its effects minimally tractable, we assume that excess demand and supply curves, and the supply curve for rail shipping are stable. The effects of this improvement can be traced as shown in Figure 4. Even with these assumptions the effect of waterway improvement propagates itself throughout the entire system. The shift in S_w from $S_{w,0}$ to $S_{w,1}$ leads to a shift of the composite marginal cost curve from $S_{q,0}$ to $S_{q,1}$, which in turn implies a new "full" marginal cost function, $FS_{q,1}$. This serves to establish a new equilibrium with the excess demand curve, giving $Q_{trade,1}$ as the new shipment volume and a new trading price of $P_{trade,1}$. As before the split of $Q_{trade,1}$ between water and rail is established where:

$MC_{q,1} = MC_r = MC_{w,1}$

The first set of benefits generated by the improvement occurs in the supplier and buyer markets. Lower transportation costs enable consumers of existing shipments to increase their surplus by area *a* in the top diagram of Figure 4. This also induces new shipments which derive a consumer surplus given by area *b*. In the supplier market, higher demand for the commodity raises its price and supply. Thus, the producer market surplus also increases by area *c* (for existing shipments) and *d* (for new shipments). The sum of areas *a* and *c* is represented in the bottom diagram by the area *A*, while the sum of *b* and *d* is represented by area *B*.

Note that area *A* is mainly made up of surplus transfers from the transport market to the supplier and buyer markets. This represents surplus losses by the transport market. However, reductions in transport production costs due to the waterway improvement enables the transport market to gain surpluses shaded areas *C* (for existing traffic) and *D* (for new traffic). The net gain in producer surplus depends on the balance of these losses and gains. One may proceed to use Figure 4 to identify the split of the producer surplus change between water and rail, but this would make the diagram even more difficult to read. However, the following will be true. Based on the stable, upward sloping supply curve for rail, it would experience a net loss of traffic, while the waterway experiences a net gain of traffic.

ORNIM: ECONOMIC ASSUMPTIONS AND IMPLICATIONS

In this section, we identify the specific economic assumptions within ORNIM and discuss the impacts of those assumptions on estimates of with-project benefits. We also discuss spatial detail and the supply of river transport within ORNIM. Finally, we discuss the process by which ORNIM reaches an equilibrium solution.

There are three critical economic assumptions within ORNIM that merit the greatest discussion:

- The demand for individual movements is provided exogenously and is perfectly inelastic with respect to the price of river transport.
- The willingness-to-pay for individual movements on the river is equal to the least-cost alternative rail rate, which is provided exogenously.
- The supply of rail for individual movements is perfectly elastic at the given rail rate.

We now consider each of these assumptions in terms of its motivation, implications for biasing estimates of with-project benefits, how the assumptions might be relaxed, and the potential benefits of relaxing the assumption in terms of providing less biased and/or more accurate estimates of with-project benefits.

Demand for Individual Movements is Perfectly Inelastic and Willingness-to-Pay for Individual Movements is Equal to the Least Cost Rail Alternative

Motivation

In the current Ohio River Mainstem Study, ORNIM considers some 8,000 annual potential movements covering nine commodity types. In the short-run, the assumption of perfectly inelastic demand is quite reasonable. A recent empirical study [*Bray, 8*], which surveyed a broad sample of shippers on the Ohio River, concluded that "one response elicited from essentially all of the respondents is that shipping decisions are not made based on transportation savings alone, rather, total cost must be considered in any decision to shift modes." Bray offers numerous examples of specific movements that have little or no opportunity for movement to rail or truck. Bray also considered willingness-to-pay in his survey. With respect to the question of the maximum willingness-to-pay for barge transportation on the Ohio River, Bray concludes that "The answer…varies by industry group." He cites one example, coil steel, that may "shift from barge to rail for a small rate savings." This is generally true if the "commodity has a high value, is not dangerous to the general public, and moves in fairly small quantities." However, Bray's general conclusion leans in the opposite direction. "In total though, most shippers on the Ohio

River Basin's navigable streams made a major location decision to move there and would pay much more than the least costly rate to maintain barge transportation."

The assumption of perfectly inelastic demand and willingness-to-pay is more relevant in the long term. Unfortunately, long-run decisions to ship by water are very complex and depend on numerous factors. The price of river transport is only one of many factors to be considered. For example, coal, which is the highest volume commodity shipped on the Ohio River, is likely to be more sensitive to environmental regulations and energy policy than to river rates. This is not to suggest that the price of river transport is not important, but rather to suggest that future demands for commodity shipments on the river are best considered exogenously to ORNIM. Recently, the Corps has improved the analysis process by adopting a scenario-based approach to project river demand.

So how do these two assumptions bias estimates of with-project benefits? As shown below, in the strictest theoretical sense, with-project benefits will be larger by assuming perfectly inelastic demand. By assuming perfectly inelastic demand for individual movements, we assume that shippers will be insensitive to the increasing cost of delay up to the point where the total cost of river transport is equal to the least-cost rail alternative. However, the issue is complicated by empirical findings, such as Bray's, which indicate that the willingness-to-pay may, in fact, be as likely to be above the least-cost rail alternative as below it. The bottom-line answer is that one cannot conclude that these assumptions bias with-project benefits positively or negatively. The direction of the bias depends on the specific movement and is best estimated empirically.

Two additional complications should be mentioned. First, our graphical model suggests that in a purely competitive market in which river and rail are perfect substitutes, the price of river transport will be set by the price of the rail alternative. In reality, river rates are often significantly below the rail alternative; thus, there is a question about who reaps the surplus gains provided by river transport – producers or consumers. While interesting, this is an equity consideration that is outside the scope of ORNIM. Second, recall that the purpose of ORNIM is to estimate the benefits of with-project conditions, as compared to the without-project case. ORNIM is not designed to estimate the total value of the Ohio River System, i.e., the benefits that would be foregone if the river system did not exist. Although, there is not sufficient space to address this issue here, the authors argue elsewhere [*2*] that the assumptions about willingness-to-pay and demand elasticity are of lesser importance if ORNIM's purpose is limited to estimating the difference between with-project and without-project conditions.

For an empirical model like ORNIM, implementing the decision process discussed in Sections V and VI represents an arduous task. It implies the derivation of demand and supply functions for each movement and economic agent at each stage of the decision process, and integrating these into a consistent framework. As a result, transportation cost benefit analysis (CBA) employs certain simplifying assumptions. These assumptions and their effects on the benefits measurement are discussed below:

Implications of Assumption 1: Individual Movements are Perfectly, Waterway Price Inelastic

This assumption simplifies the CBA by eliminating the need to estimate demand functions for individual movements, i.e., O-D/Commodity combinations. It also allows the waterway to be analyzed apart from the simultaneous decision process of the freight transportation sector. Waterway improvements, all other things being equal, would not induce new waterway traffic. This does not imply that traffic on the waterway cannot change, but that such changes are not determined by waterway costs.

Figure 5.a illustrates the initial equilibrium in the waterway transport market based on Figure 4, while Figure 5.b illustrates the implication of the above assumption. The effect on waterway improvements benefits can be derived as follows. If there is no change in waterway traffic, the measurement of net benefits is trivial, and is simply the area between the two water transportation supply curves at $Q_{w,0}$ (area A). However, it is more likely that the exogenously specified demand for waterway transport for this movement under a specified scenario is $Q_{w,1}$ rather than $Q_{w,0}$. By extending the two supply curves to $Q_{w,1}$ one may proceed to calculate the net benefit by the area between the two curves at $Q_{w,1}$, as before (area A+B). However, this raises a bounding problem since this assumption allows us to extend and/or raise the supply curves infinitely, i.e., *the movement will pay any cost to stay on the waterway*. Needless to say, this can produce large and unrealistic estimates of waterway improvement benefits. To prevent this, the price of waterway transport must be bounded from above. In essence, we need to determine the willingness-to-pay (WTP) for water transport at each movement size.

Implications of Assumption 2: WTP for Individual Movements is the Price of the Alternative Mode

As substitutes, rail and water play the role of bounding each other's price levels in the transportation market illustrated in Figure 4. As a result, the price of rail is the natural candidate for the maximum WTP for water transport. This changes the effect of Assumption 1, for each movement, from staying on the waterway at all costs to *staying on the waterway up to the price of the least cost alternative mode*. Beyond the price of the alternative mode, the behavior of the movement is undetermined, and is irrelevant to the benefits of the waterway improvement.

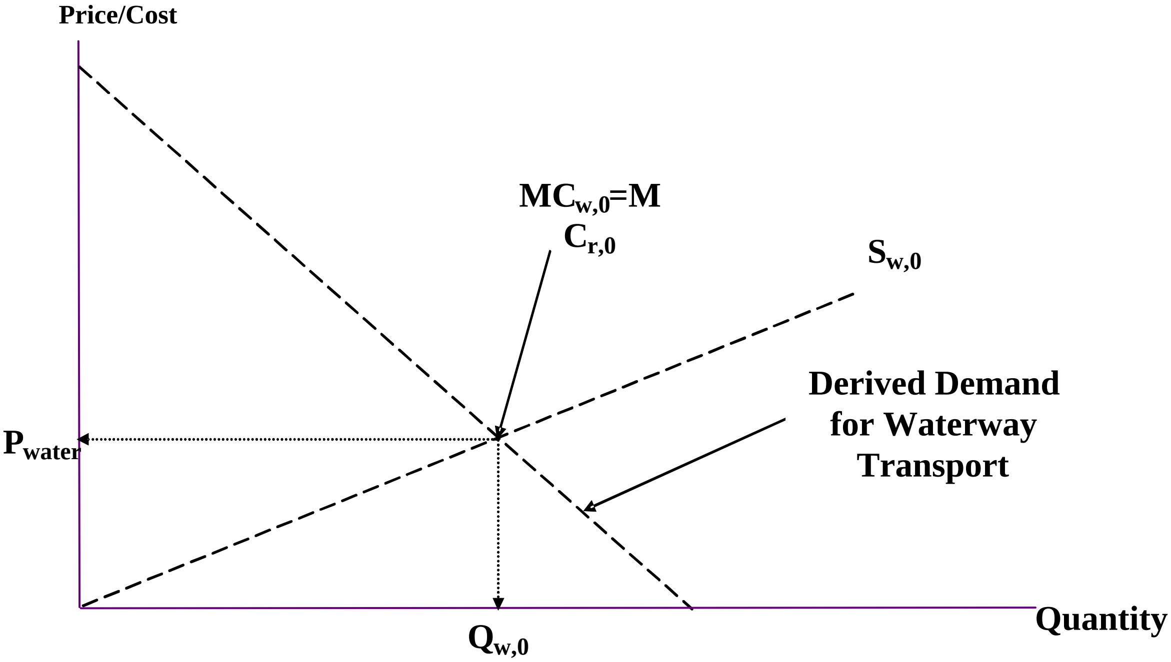

FIGURE 5a Initial Waterway Market Equilibrium

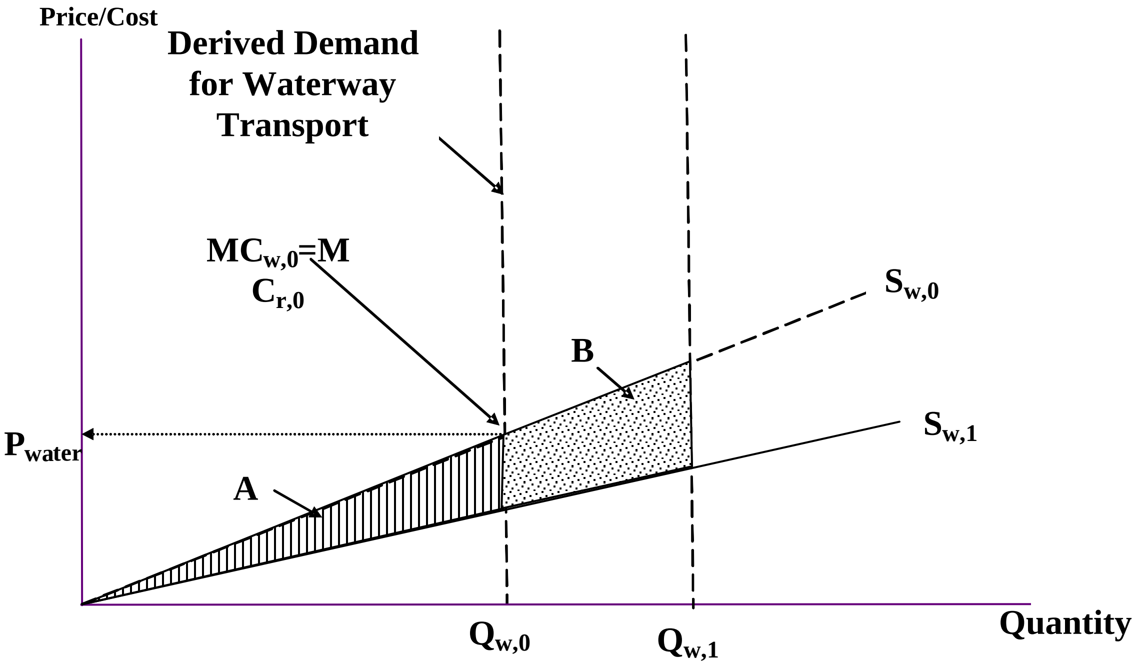

FIGURE 5b Waterway Traffic Equilibrium: Perfectly Inelastic Demand

The Supply of Rail Is Perfectly Elastic at the Exogenously Given Rail Rate

Motivation
River transport represents only about 5 percent of total freight transport in the United States, although this percentage varies considerably by commodity and region. The assumption of perfectly elastic supply of rail at the given rail rate is one of the more difficult assumptions to justify within ORNIM. Some cursory evidence, especially in the area of the Upper Mississippi and Illinois Waterway System, suggests that excess rail capacity is not available. While possibly difficult to justify, the key question here is the bias imposed by this assumption on ORNIM's estimates of with-project benefits. As is shown in the below discussion, this assumption unequivocally biases ORNIM's estimates of with-project benefits downward.

Implications of Assumption 3: Perfectly Elastic Supply of Rail at the Existing Rail Rate
In the absence of rail transport supply functions for estimating the WTP at each and every movement size, an option is to employ a point estimate of the WTP over all movement sizes. This implies a flat supply curve for rail, i.e., perfectly elastic supply of rail at the estimated price level for each movement. The overall effect of the above three assumptions is illustrated in Figure 6. The movement's net benefits will be overestimated by area C (for new traffic).

The above effects can be shown to be quite minimal in the context of this analysis. First, the more inelastic the movement's actual demand curve, the less the error (over-and under-estimation) of total benefits, i.e., WTP increases with inelasticity. Second, the purpose of this analysis is to calculate the net benefits of improvements to the waterway. The main source of overestimation then is area C, but this is minimized because new traffic will be expected to be small relative to the total system.

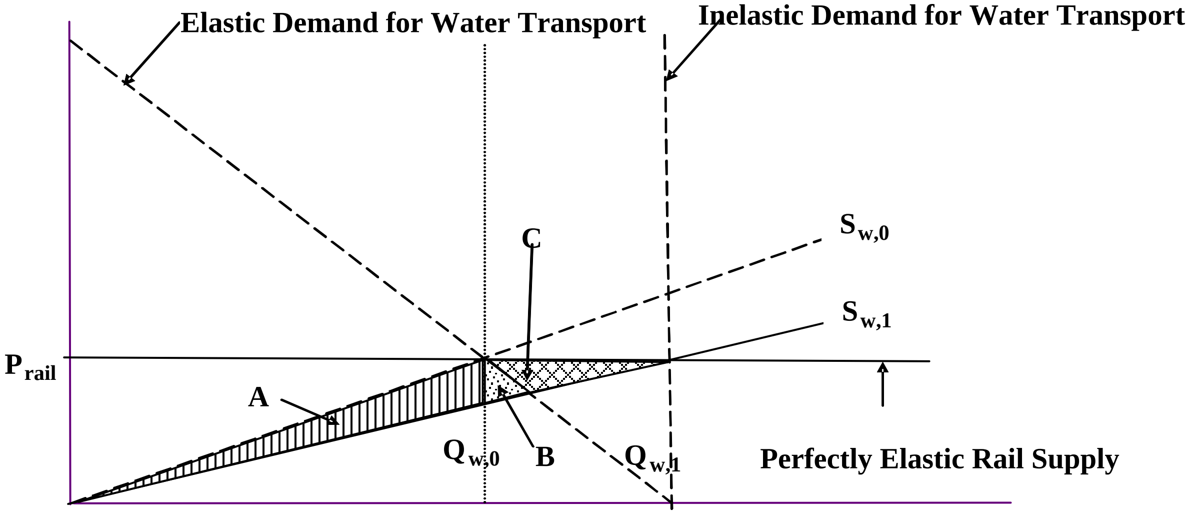

FIGURE 6 Effect of Assumptions on Movement Benefit Estimates

Spatial Detail in ORNIM

ORNIM uses a link-node representation of the Ohio River System to model waterway movements in considerable spatial detail. Origin-to-Destination (OD) movements are modeled on an annual, commodity specific basis. The current model accommodates nine different commodity classes and some 8,000 OD pairs. Origins and destinations are defined on the basis of shipper and receiver surveys. Base year waterway-inclusive and overland (rail, truck, truck-rail) transportation rates are key inputs to ORNIM. These are provided exogenously to the modeling system in the form of OD and commodity class specific rates, also based on survey data. For the purposes of modeling future year movements on the waterway ORNIM computes detailed commodity class and OD specific movement costs, for each year and each waterway improvement scenario modeled. These costs are obtained by multiplying each commodity and OD specific tonnage moved in a given year by an appropriate waterway rate. This rate is computed for each movement as a combination of fixed and delay-driven costs. The primary cost factors are:

- The costs of towboat operations including fuel, labor, other variable costs including lockage fees, and yearly fixed costs
- The fixed annual costs and hourly rate for barges
- The time required for transiting each reach of the river at the estimated speed
- The time required for loading, re-fleeting and unloading operations
- The transit time for each lock traversed en route. (This is determined by the total tonnage of all movements traversing that lock in a given year and given the type of lock closures simulated in ORNIM for that year).
- Empty backhaul costs for movements with dedicated barge fleet

Using historic traffic statistics, the model is calibrated to produce traffic flows as similar as possible to the historic baseline. The base year estimated costs are compared with the observed base year waterway rates and the difference is used as a correction factor in all future cost estimations. OD specific overland costs (per ton, per commodity class) are held static throughout the modeling process. The lock transit times (see below) are highly non-linear once congestion builds on the river system, while operating costs also contain lock transit time sensitive components.

Supply of River Transport and Equilibrium within ORNIM

The problem of defining "supply" in transportation economics is well documented. The principal difficulty lies in constructing a supply curve that captures the interplay between service quality, demand response, and the resources that need to be allocated to meet this service-based demand. Compounding this problem in the case of transportation, both price and non-price attributes of transportation service, and notably travel times, are important in determining demand [*9*]. Where significant congestion exists on a transportation system this interplay between demand, service quality, and resource allocation can become quite complex. The approach used in ORNIM is a common one of developing a suitable demand function to reflect user responses to specific service conditions: where such demand and service conditions reflect in this case a particular level of resource investment in waterway navigation. Altering this level of investment, for example by expanding lockage capacity, changes the waterway's performance, which in turn alters the demand for waterway services. Waterway supply is determined by the equilibration of these demand-service-investment decisions.

ORNIM assigns the marginal movements through an iterative process based on Wardrop's First Principle [*10*]. This "user equilibrium" principle states that the volume of traffic on a congested transportation network is distributed across alternative routes such that all routes used between any origin-destination pair have the same transport cost, while all available but unused routes have a higher transport cost. In this application, each marginal movement has a choice between a waterway route and an overland route. At equilibrium, the marginal movements assigned by ORNIM to the river system have a positive savings, the movements assigned to land would have a negative savings if left on the river, and the movements that have their tonnage split between land and water have zero savings.

Figure 7 illustrates how a solution obtained in ORNIM might affect a specific OD movement, in this case for a simple three link waterway inclusive routing versus the usual single link representation of an overland route. First, note that the fixed nature of this annual OD demand is represented by the width of the horizontal axis. This is given as volume Q. In the base year all Q tons are assigned to the waterway, for all ODs, since these are observed waterway tonnages at this point. In this example of a future year condition the average waterway cost per ton (= the sum of link 1, 2 and 3 costs) equals the average overland cost (link 4) at volume Y. In ORNIM the overland costs per ton are assumed to be constant across the range of interest. For a fixed OD demand of Q tons and an average waterway cost given by the curve "ACw before" the result is shown as a modal split of Y tons on the waterway and the remaining Q-Y tons on the overland alternative. Changes up or down in the commodity and OD specific costs of waterway transportation may result in a modal diversion from or to the waterway in future years. When significant changes occur, such as with the addition of new lockage capacity, then a new waterway equilibrium between each OD's average cost curve and its waterway demand curve needs to be found. Figure 1 also shows how a drop in waterway cost per ton causes a modal diversion to the waterway from the overland mode. If a lock expansion, for example, causes the average cost per ton to now follow the curve "ACw after" then ORNIM will assign Z tons to the waterway and only Q-Z tons to the overland mode.

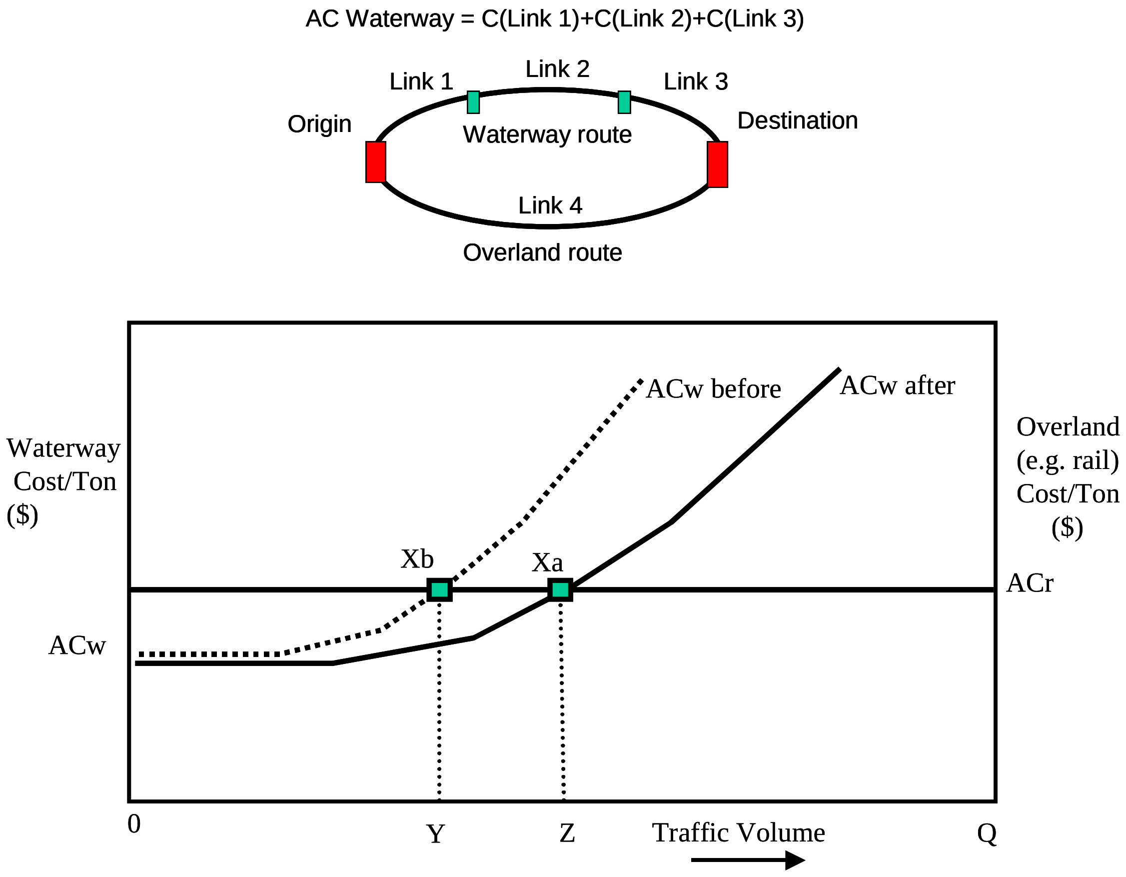

FIGURE 7 Example of a Change in Mode Split for a Deliverable Waterway OD Movement

The reason for using an approach based on Wardrop user equilibrium to distribute this traffic, rather than a simpler cost-based share equation, is that multiple ODs may share the same waterway links. Hence there is a need for a network-wide, congestion sensitive mode sharing procedure. The ORNIM algorithm obtains this solution for all OD pairs on the waterway simultaneously by taking into account all of the OD flows that may occur on any link in the waterway network. Since different commodities can have different cost savings per ton for an OD movement of the same tonnage, ORNIM is also dealing with a multi-class version of such a traffic assignment [*11*, *12*] . This is handled in ORNIM by equilibrating the modal splits over each commodity class within each OD movement. This means that while each ton assigned to a specific waterway link in a given year has the same influence on total traffic delays, no matter what commodity is being shipped, the decision to allocate this tonnage to the waterway depends on both its time-dependent and non-time dependent components of transportation cost.

POTENTIAL MARKET FAILURES

River transport, like most markets, is subject to market failures; and models such as ORNIM should consider the implications of these failures. Four market failures are of particular importance to river navigation: congestion externalities, other externalities (environmental, health, safety, national security, etc.), imperfect information and uncertainty, and public goods.

Congestion Externalities

A common and costly negative externality in waterway transportation is traffic congestion. This occurs where demand temporarily exceeds the supply of waterway capacity and as a result long queues of vessels build up at river locks. In such conditions each vessel in the queue is increasing the travel time for every other vessel. This extra time leads to extra wages and inventory carrying costs. It is often the case that a more efficient use of the transportation system might come about if some users were to change their transportation behavior by using different modes, routes or schedules. This situation occurs because users (shippers) are basing their behavior on their perceived average costs of operation, ignoring their effects on others. The result is that the cost of the marginal system user goes up, sometimes quite sharply. Many economists see this as an argument in favor of congestion fees, which are an attempt to bring about more efficient system-wide behavior. (See [*2*] for more details.)

ORNIM is capable of assessing the potential impacts of a congestion fee on system benefits, but it is not currently equipped to estimate optimal congestion fees. Modifications are planned to give ORNIM the capability to estimate optimal congestion fees.

Other Externalities

Inland navigation studies do not normally consider externalities or include external costs and benefits as NED benefits. However, to the extent that externalities differ among the mode options, a strong argument can be made to include them in the analysis and in the calculation of NED benefits. Externalities include environmental damages (e.g., air pollution, water pollution, noise, visibility, global warming, and effects on plants and wildlife), human health (e.g., mortality and morbidity resulting from accidents, pollution, and occupational injuries), congestion (e.g., highway delays and safety impacts resulting from increased traffic), and impacts on transportation infrastructure (e.g., damages to roads and bridges).

Some studies suggest that these externalities are demonstrably non-trivial [*13*]. The current omission of these impacts results in a failure to optimize the overall transportation network and is likely to underestimate the true social value of the river system and the social value of potential river system improvements.

In the past, public decision makers have been hesitant to include externalities in their evaluations of NED benefits and in making decisions about infrastructure investments. These concerns are due in part to measuring the dollar magnitude of externalities. However, recent developments within academic, legal, and regulatory circles dissipate these concerns. Externalities are now widely recognized as being essential to public decision making; and recent improvements in capabilities to identify, measure, and value externalities in dollar terms have led to the widespread incorporation of externalities in public decisions about, for example, electric power generation, oil import dependence, and environmental cleanup [*14, 15, 16*].

ORNIM is currently equipped to include some dollar-valued waterway and overland externalities in the selection and assessment of optimal lock investment plans. However, externality estimates must be generated exogenously.

Imperfect Information and Uncertainty

For a free market to be efficient, there must be no market failures associated with imperfect information or uncertainty. Under certain assumptions, markets are efficient even in the presence of uncertainty; but one must assume that all risks can be insured against.

This type of market failure exists to some extent in all markets, but may be of particular importance to inland navigation. As discussed above, the benefits of with-project conditions are measured in terms of reducing congestion and delay time. Some river system closures and associated delays are quite predictable, given that the Corps routinely announces planned closures far in advance. However, some closures are unplanned, resulting from failures of system components or floods.

This type of market failure is important for two main reasons. First, to the extent that unplanned closures result in greater delays and costs to shippers, as compared to planned closures, models will underestimate the benefits of a reliable navigation system. Additional work is needed in this area both from theoretical and empirical perspectives. Second, this market failure is closely tied to recent discussions about traffic management. (See [*17*] for more details.) Some have argued that system delays could be reduced by traffic management/scheduling.

ORNIM does not currently address the costs of unplanned delay, as separate from planned delay. This omission may significantly underestimate the benefits of a more reliable river system, which may result from new construction, additional maintenance, and/or additional rehabs. Neither is ORNIM equipped to address traffic management/scheduling. Modifications to ORNIM to address these issues are currently under discussion.

Impure Public Goods

Public funding for inland navigation and rail capacity continues to be a public policy issue, and its validity depends on another type of market failure – public goods. The recent TRB report, “Freight Capacity for the 21st Century,” [*18*] discusses the economic foundations for subsidizing rail and navigation. Building upon their argument, inland navigation is a form of impure public good. In the case of a pure public good, i.e., the case where additional consumption by one person or firm does not reduce the consumption by another (e.g., national defense and clean air), economic theory suggests that the full cost of the infrastructure should be paid by the general public. In the case of impure public goods, of which inland navigation is one, the issue of who should pay for new construction, major rehabs, and maintenance is less clear. Towing companies operating on the inland navigation system have paid a federal excise tax on fuel since 1981. These funds are credited to the Inland Waterways Trust Fund, and one half of all expenditures on inland navigation improvements are paid from the Trust Fund. The balance of expenditures for construction, major rehabs, and 100 percent of maintenance costs are paid from general federal revenues.

ORNIM addresses this issue indirectly. WSDM includes the cost of the federal excise tax on fuel in determining which potential movements move by water or rail. Thus, ORNIM can be used to assess the potential impact of a higher or lower fuel tax. ORNIM does not address what portion of these expenditures should be paid by towing companies and what portion should be paid by the general public. Note that the recent TRB report also points to public funding for rail capacity and highway expansion for trucks. Economic theory provides arguments for such subsidization, but the empirical question of the portions of expenditures to be paid by public and private funds remains an issue of public debate.

CONCLUSIONS

The objective of ORNIM is to estimate the benefits of improving the navigation infrastructure of the Ohio River System and to balance those estimated benefits against the estimated costs of improvements. By doing so, ORNIM can suggest the optimal set of infrastructure investments over time. The economic foundations embedded within ORNIM, presented in this paper, defend the appropriateness of ORNIM in meeting this objective. This is particularly true given (1) the requirement that ORNIM be consistent with Principles and Guidelines; (2) that ORNIM make maximum use of available data; (3) that ORNIM is designed to estimate the benefits of relatively small improvements to the river system, as compared to estimating the total value of the system; and (4) the Corps’ objective of being conservative in estimating the benefits of future investments in the Ohio River System.

ORNIM is a spatially-detailed partial-equilibrium model, which incorporates some strong, but nonetheless appropriate, economic assumptions. Three assumptions are critical: (1) the demand for individual movements is provided exogenously and is perfectly inelastic with respect to the price of river transport; (2) the willingness-to-pay for individual movements on the river is equal to the least-cost alternative rail rate, which is provided exogenously; and (3) the supply of rail for individual movements is perfectly elastic at the given rail rate. In the strictest theoretical sense, the first assumption biases upward estimates of with-project benefits. However, empirical evidence on the elasticity of demand and willingness-to-pay suggests that these assumptions are reasonable, especially in the short-run. In the long-run, empirical evidence suggests that decisions to move cargo by water, as opposed to rail or truck, are only partially dependent on river rates. Of equal or greater importance are other factors, such as environmental and energy policies. As such, the demand for water movements is appropriately determined exogenously to ORNIM, and the Corps’ recent scenario-based approach to demand projections is to be applauded. While the combined impact of the first two assumptions is an empirical question, the third assumption unequivocally biases downward ORNIM’s estimate of with-project benefits.

Like any empirical model, ORNIM can be improved. ORNIM is not currently equipped to estimate optimal congestion fees, to properly address other externalities, to address traffic management options, or to properly address the value of system reliability. Plans are underway to incorporate these capabilities within ORNIM – including the linkage of ORNIM with the Navigation Predictive Analysis Technique (NAVPAT) Model. NAVPAT is an environmental model, and the ultimate objective of the model integration is to estimate the shadow price associated with specific environmental constraints. While these model improvements are a logical next step, improvements in data quantity and quality are possibly of greatest need. ORNIM, like other navigation models, are data constrained. Without significant data improvements, attempts to relax the economic assumptions within ORNIM would be of questionable value.

ORNIM represents a new generation of navigation models and is much superior to the models it replaces. Nonetheless, future model and data enhancements are needed as the public and decision makers ask more detailed and complex questions and as the overall transportation system becomes more integrated and complex. Economic globalization, inter-modal transportation of cargo, the melting of regional boarders, and public demands that externalities be included in the equation call for innovative modeling approaches to provide the best and most accurate information to decision makers as they decide the future role of our inland navigation system.

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