A Research Program for Modeling Strategic Aspects of International Container Port Competition

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Abstract

As national economies globalize, demand for intercontinental container shipping services is growing rapidly, providing a potential economic boon for the countries and communities that provide port services. On the promise of profits, many governments are investing heavily in port infrastructure, leading to a possible glut in port capacity, driving down prices for port services and eliminating profits as ports compete for business. Further, existing ports are making strategic investments to protect their market share, increasing the chance new ports will be overcapitalized and unprofitable. Governments and port researchers need a tool for understanding how local competition in their region will affect demand for port services at their location, and thus better assess the profitability of a prospective port.

We propose to develop such a tool by extending our existing simulation model of global container traffic to incorporate demand-side shipper preferences and supply-side strategic responses by incumbent ports to changes in the global port network, including building new ports, scaling up existing ports, and unexpected port closures. We will estimate shipper preferences over routes, port attributes and port services based on US and international shipping data, and redesign the simulation model to maximize the shipper's revealed preference functions rather than simply minimize costs. As demand shifts, competing ports will adjust their pricing (short term) and infrastructure (long term) to remain competitive or defend market share, a reaction we will capture with a game theoretic model of local monopoly that will predict changes in port characteristics. The model's hypotheses will be tested in a controlled laboratory experiment tailored to local port competition in Asia, which will also serve to demonstrate the subtle game theoretic concepts of imperfect competition to a policy and industry audience. We will apply the simulation model to analyze changes in global container traffic in three scenarios: addition of a new large port in the US, extended closure of an existing large port in the US, and cooperative and competitive port infrastructure development among Korean partner countries in Asia.

Keywords: Port competition, investment game, port overcapacity, shipper behavior, port choice, port demand simulation

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Introduction

As national economies globalize, demand for intercontinental container shipping services is growing rapidly, providing a potential economic boon for the countries and communities that provide port services. The promise of permanent well-paying jobs at the port, in complementary hinterland transportation services, and possible export-related economic development, as well as temporary jobs in port construction, draws many community leaders to propose investing considerable public resources in port development, under the belief that if they build a port, there will be shippers to use it. Because successful large, hub ports (planned to accommodate new ultra-large container ships) generate the most economic activity, they are the focus of most development efforts. While unprecedented recent economic development in Asia has largely filled available ports, in other parts of the world this race to build has lead to overcapitalization of port resources and significant losses of public funds (e.g., Cyprus); the port boom in Asia could lead to similar losses if economic growth slows.

Ensuring that public investment in port development actually leads to the intended increase in economic activity requires developing a careful plan for port and hinterland infrastructure. Key to developing that plan is understanding two factors: whether the proposed port has the features and services that will draw shippers to use it rather than other ports in the region, and whether there are actions (e.g., lowering prices or investing in their infrastructure to become more competitive) that incumbent ports can take to defend their market shares. While existing planning methods (focus groups, public meetings, user consultations) are well designed to plan facilities which will appeal to customers, the potential for responsive investment on the part of competitors is frequently not considered in the process, and the extent to which demand can shift is not well understood. Our approach will develop a formal, theoretical and an applied, data-driven model for integrating into cargo transportation planning strategic factors in determining investment in port infrastructure.

Project Objectives

Our broad objective is to assist planners in determining whether they can capture and profitably defend shipping market share as a hub, traditional land-sea cargo port, or regional feeder port. While this is a long-term research program, we propose to begin by developing and estimating empirical and theoretical models that will lay the foundation for future work, and an eventual tool for use by planners. To wit, we will

1. Improve our understanding of shippers' port choices by estimating how demand shifts among ports as a function of port and hinterland features;
2. Identify how incumbent ports can defend their market power by developing a game-theoretic model of infrastructure investment and local monopoly, tested with a controlled economic experiment;
3. Extend our existing port demand simulation model to reflect shipper preferences;
4. Evaluate specific port development scenarios of current policy interest by applying the simulation model to determine payoffs for key ports under different strategic development responses in the game theoretic model.

While the resulting model of market entry and demand for port services will aid planners in determining the proper investment scale for new ports in a competitive environment, it will also help them determine whether there are additional gains from cooperative development, and in assessing the effects of service interruptions among existing ports, due to labor dispute, accident, natural disaster or other event.

Task Descriptions

We propose to approach our objectives through four phases. The first two phases focus on developing theoretical and empirical inputs into a global port demand simulation model: phase I will conduct a statistical analysis of port choice data to enhance our understanding of factors which determine port selection, and phase II will develop a strategic model of port investment to capture and protect market share. In phase III, we will extend our existing port demand simulation model to reflect the results of phases I and II. The fourth phase will apply the simulation model to evaluate demand under key scenarios, including cooperative investment in Asia, and expansion or closure of key ports in the US.

Phase 1: Obtain estimates of demand for port services throughout the global network

In this phase, we will use data on shipment routing to determine the factors that enter in shippers' decisions about which ports to use, and thus understand how their choices would change in the face of changes in the global port network.[1] There have been a number of (older) qualitative analyses of shipper behavior and route choice, which are useful in identifying key variables. For example Murphy and Daley (1992; 1994) conduct a survey of people at different points in the supply chain, and identify tracking information, loss/damage performance, cost, equipment availability and convenient pickup/delivery as being key variables. While this provides a starting point, all these variables may not remain important when looking only at containerized cargo. Bichou and Gray's (2005) review of terminology also provides a descriptive starting point for model variables.

In contrast to these qualitative studies, statistical analysis of actual port choice data using methods similar to those proposed for Phase I allows researchers to identify not only which factors are (statistically) important, but also to quantify their importance. Discrete choice techniques were developed by McFadden (1974) to gauge demand for the Bay Area Rapid Transit train network around San Francisco, and popularized for transit demand research by Ben-Akiva and Lehrman (1985). Bierlaire (1998) provides a more recent summary of discrete choice approaches and their applications to transportation behavior analysis and forecasting. Winston (1981) conducted one of the first port choice models, using a multinomial probit analysis to predict the demand for domestic ocean container service. Tsamboulas (2000) uses a combination of statistical methods to correlate behavioral and perceptual factors related to the use of intermodal transportation with the physical and economic criteria to which modal choice approaches are usually confined.

Application of discrete choice models to container transportation is a relatively recent, mainly because of the computational complexity of the problem because number of alternatives is relatively large and very detailed data on ports and shipments is required. Veldman and Buckmann (2003) use a logit model to quantify factors affecting cargo routing decisions, including transport cost, transit time, services frequency and indicators of service quality. Based on the estimation, they derived a demand function to be used for port traffic forecasting in four major ports around Rotterdam (Antwerp, Bremen and Hamburg). The estimated demand function was the basis for the economic and financial evaluation of a container port expansion project. However, this study did not consider the global source of the cargo, and it did not take adequate account of the variation of route selection behavior for different commodity types. For international shipping, liner rates will be an important factor in cost, and Brooks and Button (1996) provide a sense of determinants of shipping rates.

For the Asia-pacific region, Tiwari et al (2003) used a nested discrete choice method to analyze shipper's behavior for containerized cargo in China. This study modeled the port and shipping line choice behavior of shippers in China, using a shipper-level database obtained from a 1998 survey of containerized cargo shippers. The model includes 10 shipping line and port combinations as the total choice set, nesting the choice of ports within the choice of Chinese and non-Chinese shipping lines. This study indicates that the most important variables are the location of the port as expressed by the sea transportation time and cost, and land transportation time and cost, port characters including number of ship calls, total TEU handled at the port, TEUs of cargo per crane, TEUs per berth at port, usage factor (handling volume per length of quay), the number of routes offered, and port loading charges.

Nir, Lin and Liang (2003) use a logit model to capture the distribution of export activity among Taiwan's three ports. They find that generalized measures of travel time and cost to the ports were significant. In

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[1] We conceptualize our model in terms of a shipper's choice because our interviews with industry and port officials indicate shippers and expediters have considerable control of where shipments are loaded or offloaded, often even changing destination ports while containers are *en route* to save time. However, we recognize that there is variation in the industry as to who makes the actual routing decision, shippers who choose liners and thus routes, or liners once they have a transportation agreement with a shipper. Since we are modeling actual observed container movements, we are actually modeling the demand functions of whoever is making the choice, so our model will be accurate even if our necessarily concise explanation is oversimplified.

contrast to Tiwari et al., they find service frequency was not a significant factor. While they observe that ports are competitive, in that shippers do not always choose the port closest to them, the analysis does not capture the drivers of those choices.

Malchow and Kanafani use a logit (2001) and nested logit (2004) discrete choice models to analyze the distribution of maritime export shipments among US ports. This study selected four commodity-types (bulk materials, foods, fabrics and manufactured goods) in one month of PIERS data, exports to eight foreign countries, and eight US ports including Charleston, long Beach, Los Angeles, Port of New York, Oakland, Savannah, Seattle, and Tacoma. The variables in this model include both attributes that determine transit time and attributes that affect the total transit cost. In addition to the variables that were significant in other studies, they identify sailing headway (average time between sailings on a route at a particular port), cargo type and the probability of being the last port of call are significant factors in shipper choice.

We will conduct the analysis on a continental basis, using original separate analyses for the US and Asia; we will adopt Veldman and Buckmann (2003) for European results. For each region, we will obtain data on the routing for a wide range of import and export shipments. For each shipment, we will use the origin (foreign port for imports, domestic city for exports), destination (domestic city for imports, foreign port for exports), routing, timing, value and other manifesto information for every container processed at major ports in the coverage area. We will combine this shipment-specific data with data on port attributes previous studies have suggested are important to port selection (Malchow and Kanafani 2004; Murphy et al. 1992; Murphy and Daley 1994). These include physical characteristics (e.g., berth size, channel depth); productivity measures (e.g., crane speed, number of cranes); size of the commodity demand and supply structure in the port's hinterland; the transportation infrastructure of the port's hinterland; and commodity-specific variables. We will consult with industry collaborators to identify other relevant variables. While port service pricing data is unavailable, interviews at US ports suggest per TEU handling charges vary little (see Talley 1994), and that other charges vary with distance of piloting, shipper volume and seasonal variables that can implicitly capture price differences among ports. Supplementing these previous studies, investigator Chang is hosting, through the Global U8 University Consortium, a Seminar on Port Competition in November, at Inha Unviersity, where the investigators will meet with industry representatives, government officials, and academics to improve our understanding of demand and strategic competition.

Sidebar 1: Conditional Logit

An agent *i* is faced with a choice among *J* alternatives. Each alternative gives her utility $U_{ij} = V_{ij} + \varepsilon_{ij}$, where V_{ij} is observable utility and ε_{ij}, treated as random, captures unobserved attributes or idiosyncratic effects. V_{ij} is a function of observed attributes X_{ij}, and attribute weights, β, which indicate the relative contribution levels of each attribute make to utility.

The agent chooses the alternative that yields the highest utility, a choice that appears random to the investigator:

$$\Pr(Y_i = j) = \Pr(U_{ij} \geq U_{ik}\ \forall k) = \Pr(X_{ij}\beta + \varepsilon_{ij} \geq X_{ik}\beta + \varepsilon_{ij}\ \forall k).$$

If the ε_{ij}s are assumed to follow an Extreme Value distribution, the probability *i* is observed choosing *j* is

$$\Pr(Y_i = j) = \exp[X_{ij}\beta] / \Sigma_k \exp[X_{ik}\beta]$$

Given a large amount of data, the attribute weights β that is most likely to have generated the data can be estimated using maximum likelihood techniques.

The relationship between choice of port and these independent variables will be assessed using a conditional logit model, which has been widely used to model choices of route and mode in transportation demand (e.g., McFadden 1974; Malchow and Kanafani 2001, 2004; Veldmann and Bruckmann 2003). Conditional logit (see Sidebar 1) models the probability of choosing each port as a function of the utility (profit) the shipper would receive from using that port, which is function of shipment attributes, port attributes and other factors which are not observed.[2] In making their choice, the shippers trade off among the attributes in unknown ways, which can be measured from the data. The

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[2] One of the limitations of conditional logit modeling is that it assumes that when one alternative is removed, demand is distributed among all other alternative in the same proportion as demand when the alternative was available. This might not accurately capture substitution of very nearby ports, where most of a closure at Tacoma, for example, could be shifted to Seattle. If a Hausmann test suggests it is necessary, we will use a nested logit model which accounts for correlation in demand for nearby ports (Malchow and Kanafani 2001).

estimated attribute coefficients are weights that indicate the relative importance of each attribute. We will test the hypothesis that each of the factors included in the model using a t-test of the coefficient on each factor to determine whether its effect is statistically significant.

While this analysis is of interest in itself, as knowing more about preferences of shippers will help port managers identify investments that will most affect their appeal to customers, our goal is to integrate these preferences into a global demand model. Hence, we will conduct separate analyses to identify the preferences of US and key foreign trade partners. For the US, we will directly transfer results from a current related project of Anderson and Grigalunas, which uses precisely this method to analyze demand for US ports. Asian data will be obtained through efforts of Korean collaborators and through the Korean PORTMIS (Port Management Information System), which maintains similarly thorough database of manifest data, and will be analyzed as part of this project.[3] While the US and Asian groups will approach this task for their respective data, they will be importantly linked by the lead investigators and the need to supply inputs to the demand simulation model in Phase III.

The conditional logit modeling will yield information on the preferences of shippers for port attributes, allowing us to predict how they will react to new ports, closed ports, or changes in attributes of existing ports. This reaction can be captured by changing the attributes for a port (or shipment) and using the estimated coefficients to predict choice probabilities. The demand for each port will be the expected number of containers, given the port attributes resulting from each investment scenario of interest.

Phase II: Develop and test a model of spatially specific port development competition

In this phase, we will develop and test a theoretical model of port authorities' strategic responses to changes in demand caused by investment of competing ports, or loss of capacity at competing ports. Ports compete with one-another by investing in infrastructure that makes them more appealing to shippers seeking service to their hinterland. Unlike in a standard perfectly competitive market, the investment and pricing decisions of individual ports can affect the market for service, and the extent of that effect depends on the actions of the port of interest, and of the other ports in the region. Such environments where the payoffs of economic agents depend on their own decisions and on the decisions of others are the domain of game theory. As with any modeling exercise, we will simplify the situation to capture the key incentives associated with competition and development; economics is a science of reducing behavior to simple models, and we continue to use simple models because they provide useful insights.

A number of analyses develop models of competitive aspects to ports, but they typically consider infrastructure investment to be an exogenous market (rather than endogenous strategic) phenomenon (e.g., Nir, Lin and Liang 2003; Hanelt and Smith 1987). An exception is Zan (1999), who constructs a multi-level market game of port service prices, and liner scheduling and pricing, and shipper liner choice. In the leader-follower game developed, the port administrator selects a level of infrastructure and port service prices, the shipper then sets routes, frequencies and transport prices, and shippers then select liners based on time and price. While this model is extremely detailed, and not a pure Stackelberg game as it is described (the players differ in role in the process, and are not simply competitors offering prices on substitute goods), it is one of the few applications of game theory to port service competition.

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[3] To our knowledge, China does not maintain a similar national database.

This phase will be accomplished in two tasks, model development and model testing. The model will be tested with a controlled laboratory experiment, in which human subjects play the role of port managers.

Task 1: Model development

Port competition includes three elements that are key to understanding competitive investment. First, it is characterized by imperfect competition, where individual ports may cooperate or compete to provide service for a given area. Whether competitive or cooperative outcomes are sustained is of particular interest to port developers in Asia. Second, port competition is spatially dependent, in that investments will generally affect competitors whose hinterlands overlap to a greater extent than more distant competitors. Third, the game is dynamic, in that it is played through time with the option for ports to make investments in different years.

While model development is the research task, we anticipate integrating elements from three basic game models to develop a single model that generates a range of predictions consistent with the incentives associated with international container port development and competition. The fundamental model of competition will be Bertrand price competition (see Sidebar 2), in which competing ports' demand curves are substitutes to some shipping customers (captured by parameter *b*). In this model, the imperfect competitors each set their price anticipating the prices that others will set. In Nash equilibrium, each port is maximizing its profit, given the price levels set by the other players.

Sidebar 2: Bertrand Competition

In the simple Bertrand model (e.g., Gibbons 1992), two firms face demand curves given by

$$q_i(p_i,p_j) = a - p_i + b\,p_j.$$

The quantity demanded from firm *i*, q_i, is determined by the p_i, the price charged by *i*, and the price charged by the competitor, *j*, p_j. If the products are not perfect substitutes, $b<1$ indicates that *j*'s price has a smaller effect on q_i than does p_i.

Both firms choose a price that maximizes their profit, given they know the other firm will do the same,

$$\max_{p_i} \pi_i(p_i,p_j) = q_i[\,p_i - c\,] = [\,a - p_i + b\,p_j^*\,][\,p_i - c\,]$$

where *c* is a constant marginal cost of production.

Differentiating each firm's objective function and solving the pair of equations for p_i^* and p_j^* yields

$$p_i^* = p_j^* = (\,a + c\,)\,/\,(\,2 - b).$$

At these prices, each firm is maximizing its profit, given the other firm's price, a Nash equilibrium.

The basic Bertrand model will be modified in two ways to incorporate incentives associated with port investment. First, the potential for competition among ports is determined (or limited) by their locations and the extent to which they are substitutes for local and hinterland markets. This can be represented in the model by setting different elasticity of substitution parameters (*b*) for different ports: those with no local or hinterland competition will have inelastic demands, and those serving similar markets will have demands which considerably affect each other. The equilibrium result will be that ports with little local competition will be able to charge higher prices (or offer fewer services), and that ports competing for the service to the same hinterland will have to lower prices or improve service to maintain market share.

The second modification to the standard Bertrand model is to integrate a competitive investment environment. For this, we anticipate drawing on two other standard games. Competitive investment in imperfect competition has been widely studied modeled with the monopoly entry game (Cooper, Garvin and Kagel 1997). In the entry game, a number of potential competitors simultaneously decide whether to pay an entry cost to compete with other entrants in a market with a downward-sloping demand curve. If few firms enter, they receive a high price, enough to recover their entry cost and make a profit; if many firms enter, the price is low and entrants may not recover their entry cost. In equilibrium, enough firms enter that each is just able to recover their entry cost, but an additional entrant would not.

In the port competition game, the entry cost will correspond to the amount paid to develop port infrastructure, which will change the substitution elasticities (port-pair specific b_{ij}s) among ports. However, when infrastructure is being developed, it can be expanded (or not maintained) in continuous time. This dynamic element changes the game, adding incentives of a continuous all-pay dollar auction (Shubik 1971), a game where all players bid on a dollar bill, the highest bidder wins the dollar, but all players must pay their bids when the auction ends. Because at any current high bid, every player is better off raising the bid by 1 cent (because then she pays a couple cents more, but wins the dollar), in equilibrium, bidding continues until all but the winning player exhausts their budget. Similarly, ports will continue investing infrastructure to capture and defend market share over which they are competing; because prior investments are sunk costs, the additional investment required to expand or defend market share is always justified. However, because the "prize" of market share is continuous and of decreasing marginal value and constrained by increasing costs of technology and operation, the equilibrium prediction in the port game will not be as extreme as in the dollar auction.

Our analysis will look at two types of outcomes, competitive and cooperative. In the competitive Nash equilibrium, ports will invest heavily to compete with one-another. When a large number of ports are serving the same markets (as could happen in Asian export manufacturing regions, or in the US with the inland Midwestern market which can be served well by many ports), the level of investment could be so high that it cannot be recovered (without significant growth in global port demand). In a cooperative outcome, the multiple ports will coordinate on investment levels in which they achieve equal levels of profitability across the global market. The distinction between these two outcomes is of particular policy relevance, because there is concern among port experts that many governments are investing in ports in anticipation of capturing market share, but without adequate consideration for the capacity being developed elsewhere. If the parameters determining returns on investment are such that in the competitive equilibrium can lead to losses, then port development is not a responsible use of public monies; welfare improvements require either cooperative investment levels, or not entering the port services market in the first place. However, outcomes can be improved with cooperation.

Task 2: Model testing and demonstration

The theoretical model will yield a prediction of a competitive equilibria and cooperative outcome of the port investment game. In our experience doing modeling for policy, nonacademics often have a hard time utilizing such purely theoretical results. This is especially true when the model yields counterintuitive results, such as when all or almost all investors lose money. People often wonder if all people are losing money, why can't they realize this, and reach a better outcome? However, such socially inferior outcomes happen all the time: fishers overharvest fisheries, threatening the sustainability of their own livelihood and suburbanites move outside cities, contributing to congestion on their own commutes. Thus, we plan to test the hypotheses of the model, and demonstrate to policymakers the range of outcomes that may occur in the port investment game.

Our demonstration will be a controlled laboratory experiment, in which human subjects will play the role of port authorities (or governments responsible for port development), choosing levels of infrastructure investment. We will conduct two treatments, each calibrated to a different region of the world to capture different levels of competitiveness. The high competitiveness treatment will be benchmarked to the Far-eastern port market, where China, Korea, Taiwan and Japan compete to ship Asian goods to western markets. The low competitiveness treatment will be benchmarked to the US West Coast market, where container trade is dominated by LA/LB and Seattle/Tacoma, with different local and hinterland markets.

We anticipate our experimental sessions will involve 6-12 subjects, each playing the role of a significant port (or potential port) in the region, within the URI Policy Simulation Laboratory, a 26-workstation facility designed for running economic experiments. Subjects will interact anonymously through computer software developed especially for this experiment. Each subject will be given capital and investment opportunities corresponding to the level of infrastructure at her port. Through a sequence of 15-30 periods (years), each subject will select a level of investment for her port, and will receive payoffs based on the appeal of her port to shippers, given her investments and those of other subjects, as determined by the simulation model (see Phase IV); we may opt to use fewer periods and repeat the game within a session to understand the effects of learning. At the end of the experiment, subjects' earnings will be totaled and converted to US dollars, and they will be paid in cash for participating.

The experiments will generate data on investment levels and payoffs for each port, and levels of efficiency achieved within the game. These can be compared with the predicted Nash equilibrium and socially optimal (cooperative) outcomes, using a nonparametric Wilcoxon test for the distribution of outcomes. Of particular interest will be the frequency of a non-equilibrium, non-cooperative outcome commonly observed in games with intertemporal, delayed investment (e.g., Moxnes 1998) in which subjects overinvest in early periods, corresponding to a glut of capital and low prices for port services, at which ports cannot recover their investments. Demonstrating that such extreme outcomes are possible is a key contribution of the project.

Economic experiments, the technique awarded the 2002 Nobel Prize in Economics (Vernon Smith), are effective because subjects are paid their experimental earnings in cash, so just as groups who make better investment decisions in the field make more profits, subject groups who make better investment decisions in the laboratory earn more money for participating (Smith 1976; Davis and Holt 1993). Experiments have been used to test theoretical models, demonstrate ranges of possible outcomes (e.g., Anderson 2004) and compare institutions for particular applications. High profile, high value applications of experiments include designing the auction the FCC has used raise more than nine billion dollars selling licenses to bandwidth used by cellular telephones (Banks et al. 2003; Salant 2000; Plott 1997), water allowance trading (e.g., Murphy *et al.* 2000; Murphy *et al.* 2003; Cummings, Holt and Laury 2004), the rules under which the Environmental Protection Agency sells pollution permits for sulfur dioxide under the Clean Air Act (Cason 1995; Cason and Plott 1996). In the latter case, experiments demonstrated a perverse incentive that was leading to inefficiencies, and the rules were changed as a result of the experimental results. Investing in laboratory research to fully understand the incentives of competitive actors can improve policy outcomes.

Phase III: Extend simulation model of global port demand to reflect shipper preferences

In this phase, we will extend our existing model to reflect shipper preferences in container routing (Luo, 2002; Luo and Grigalunas; 2003; Grigalunas et al, 2001, 2002). The outcomes of the simulations will be used to evaluate port development and security scenarios in Phase IV.

Our existing port demand simulation models movement of all container freight imported to the US from its country of origin to its state of destination,[4] and all container freight exported from each US state to its destination country. International trade data is used to determine the imports and exports of each commodity category for each country, and the volume between each US state-foreign country pair. For each state-country pair, the model selects the route for cargo that minimizes transportation costs, including inland trucking and rail costs, at-sea transport costs, and cargo inventory costs based on the average value of the commodity. Demand at each port is the total number of containers that pass through that port on their cost-minimizing route from their origin to destination.

While this model is the state-of-the-art in modeling port demand, and is useful for characterizing the general effect of medium-scale changes, it has a number of limitations that make it insensitive to small-scale changes and poorly calibrated for large changes. First, the existing model bases preferences for one port over another only on differences in total cost for origin-to-destination transport. In reality, shippers' choice of ports depends not only on costs, but also many other factors, such as time, frequency, quality of service and risk or uncertainty of delivery. We will modify the existing simulation model to replace the cost minimization objective with the shipper objective function revealed in the conditional logit analysis from Phase I.

The second limitation of our current model is that it estimates *potential* demand, and thus has no limitations on the capacity of individual ports. Musso (1999) discusses the optimum size of port terminals, based on the trade off between increasing terminal cost and decreasing ship cost when terminal size increases. Chu (2005) summarized existing methods used in determine container yard capacity. Kia (2002) used a computer simulation approach to investigate port capacity. Capacity can be increased without major changes in infrastructure if efficiency in increased, a topic which has been widely studied. Lin (2005) summarized existing researches that measured port efficiency by applying DEA (Data Envelopment Analysis) and SFA (Stochastic Frontier Analysis), compared the these two different methods, and applied DEA and SFA analysis to 27 selected international container ports in 18 areas. Teng

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[4] The model increases geographic resolution where it is necessary, so import demand is modeled by county within New England to better identify competition for Quonset, and export sources are simplified to three key ports in Europe and one port for Africa.

et al (2004) used GRA (Grey Relation Analysis) model to evaluate port competitiveness for 8 container ports in East Asia.

Since ports have a fixed number of berths, cranes, terminal space and operation methods that constrain the number of containers they can move, service prices must increase as ports must pay overtime for longer operating hours and adopt more space efficient (but costly) yard practices; these price changes will in turn affect pricing and the quality of services. A complete supply side analysis is beyond the scope of this project, however, interviews with port experts indicates ports do not regularly change prices in response to demand, suggesting port responses to demand shifts may be reasonably approximated by imposing capacity constraints at constant prices. In our experience, port managers and terminal operators have a good sense of the current and maximum capacities—both in a short-term pulse of business and sustainable long-term—of their ports. Anderson and Grigalunas are currently collecting this data for US ports as part of an ongoing project, and a sample of Asian port managers will be contacted by our Asian counterparts for this project.

The revised model will simulate movement of shipments from their origins to their destinations; where individual shipment data is available, it will be used to identify cargo movement, and where it is not, country-aggregate international trade and consumption data can be used to determine volumes moved from origin to destination. For shipments of each commodity from each origin to each destination, the model will calculate the utility the shipper would receive from each available port, based on the logit model analysis from Phase I. It will then distribute cargo volume among ports in proportion to the predicted choice probabilities given by the logit model. If a port reaches its capacity, the shipments with the lowest opportunity cost will be shifted to their second best ports. This procedure will ensure that the global utility from shipping is maximized subject to the constraints at each individual port.

The model will yield predictions of the amount of cargo that moves through each port, given the port infrastructure and intermodal connections available at each port. From this, we can calculate the payoffs to the port authority from their level of infrastructure; the payoffs from alternative investment levels at competing ports will be used in the game theoretic model to assess Nash equilibrium and possible cooperative outcomes for different port development scenarios in Phase IV.

Phase IV: Simulate global demand for port services under scenarios for change in the port network

We will apply the empirical, theoretical and simulation models developed in Phases I-III to three scenarios of particular policy interest in the US and to our Korean partners in the project:

1. Closure of a major US port (as might be attributed to natural disaster or other incident);
2. Expansion and development of a major US port;
3. Enhanced cooperation among Korea, China, Japan and possibly Taiwan in port infrastructure development.

For each of these scenarios, we will select a port or set of ports of current interest. For the first scenario, we anticipate that the economic significance of LA/Long Beach will makes its closure of particular interest and policy importance: seismic activity in its location makes it prone to natural disaster, and its economic significance makes it a desirable terrorist target. For the second scenario, we anticipate focusing on development or expansion in of an east coast port. Recent interest in a port at Quonset Point makes it an appealing local test case, but if other east coast communities appear closer to development, we will target those options instead, as being of greater current global interest. For the third scenario, local and national Korean governments are currently considering whether and how to cooperate with one-another and other ports in central Asia, including ports in China, Japan and Taiwan to coordinate investment. We will adopt the ports that our Korean partners are mostly considering partnering with, to describe and quantify the benefits of potential cooperation.

Each scenario consists of a set of relevant ports, and investment alternatives for each port. We will apply the simulation model to determine the demand, and thus revenues and profits, for each port under each combination of investments. These payoffs will be used within the game to calculate Nash equilibrium levels of investment, and the potential relative gains from coordination of investment in a cooperative outcome, in the scenarios of interest. These equilibrium outcomes can be used to advise port authorities, local and national governments in selecting a level of port investment that maximizes profits and ensures responsible use of public economic development funds.

Discussion

The improved understanding of competition in spatially overlapping markets with cumulative intertemporal investment, and how this relates specifically to the maintenance and development of the global port network, will benefit shippers, liners, port authorities and governments around the world. For shipped goods manufacturers and liners, understanding where competition is likely to result in excess capacity of port services can help them target production locations and future ship deployments for areas with low-cost (or high-tech) port services, or with capacity of future growth. For local and national governments deciding whether and how to allocate public funds to port development, the model provides a specific framework to allow them to think about how other ports in the region will react to their investments, how demand will shift, and therefore whether they will be recover their investment. They may find that only moderate or cooperative investment is preferable to a competitive environment, and is a better use of public resources. For the specific scenarios outlined in Phase IV, alternatives and outcomes will be analyzed explicitly. Finally, the competition and demand model can help governments develop supply chain security, as the model can suggest how demand will shift if a particular port is closed for a short or long time. While recent political attention in the US has focused on terrorist attacks, such information is also valuable in planning for hurricanes, typhoons, tsunamis and earthquakes.

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