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# NEW MEASURES OF PORT EFFICIENCY USING INTERNATIONAL TRADE DATA

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## ABSTRACT

As the clearinghouses for a major portion of the world's rapidly increasing international trade flows, ocean ports and the efficiency with which they process cargo have become an ever more important topic. Yet, there exist very little data that allows one to compare port efficiency measures of any kind across ports and, especially, over time. This paper provides a new statistical method of uncovering port efficiency measures using U.S. Census data on imports into U.S. ports. Unlike previous measures, this study's methodology can provide such estimates for a much broader sample of countries and years with little cost. Thus, such data can be used by future researchers to examine a myriad of new issues, including the evolution of port efficiencies over time and its effects on international trade flows and country-level growth.

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## INTRODUCTION

As the clearinghouses for a major portion of the world's rapidly increasing international trade flows, ocean ports and the efficiency with which they process cargo have become an ever more important topic. Poorly-performing ports can substantially reduce trade volumes and may have a greater dampening impact on trade for small, less-developed countries than many other trade frictions (Clark et al., 2004, and Wilson et al., 2003). Disruptions to U.S. ports, such as the recent congestion issues at the ports of Los Angeles and Long Beach, quickly become national news because they can substantially impact supply chains throughout the country (MacHalaba, 2004). Local governments and port authorities are perhaps the most concerned with port efficiency, as ports compete with each other for cargo volume.

Despite the obvious significance of port efficiency, consistent and comparable measurement of such efficiencies is a daunting task. A myriad of factors contribute to port efficiency. Some of the more obvious factors include dock facilities, connections to rail and trucking lines, harbor characteristics (including channel depth and ocean/tidal movements), time to clear customs, and labor relations. However, both consistent data and methods that allow construction of a measure or index that allows comparisons across ports are not currently available. As stated in a recent report to Congress by the U.S. Department of Transportation, Maritime Administration (MARAD),

> "MARAD concluded that it was unable to provide the requested comparison of the most congested ports in terms of operational efficiency due to a lack of consistent national port efficiency data … comparing port efficiency would require the creation of new methodologies and the collection of data that were not available for this report" (U.S. Department of Transportation, Maritime Administration, 2005, p. 8).[1]

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[1] This study is available from the "Publication" link at MARAD's website: www.marad.dot.gov. Unavailability of port comparison measures is also echoed in the academic literature by Bichou and Gray (2004).

This concession by MARAD is of great importance as the main motivation for the report was a Congressional request for a comparison of port efficiency, not only for commercial reasons, but also for national security concerns in light of Operation Iraqi Freedom. This paper is a first attempt to provide a new methodology which is relatively simple and costless for the estimation of port efficiency over time.

The literature is not devoid of attempts to measure port efficiency. One common methodology is through the use of surveys. A recent indicator of port efficiency has been constructed from annual firm-level surveys for the years 1995 through 2000 and reported in the Global Competitiveness Report. These surveys ask firms to rank countries' port efficiency from 1 to 7, where 1 indicates that the firm strongly disagrees with the statement "Port facilities and inland waterways are extensive and efficient", whereas 7 indicates the firm strongly agrees with the statement. Other studies have used these measures and found that the measures have a strong and significant effect on trade. (Clark et al., 2004, and Wilson et al., 2004) Similarly, Sanchez et al. (2003) use survey data on port efficiency to examine transports costs to Latin American ports and find that such measures are substantial components of these transport costs and have an impact on trade flows that is similar in magnitude to that of distance.[2]

Drawbacks of survey data are, first, they rely on impressions of survey participants where observations of port efficiencies *per se* may be confounded with other factors connected with the country of the port's location. Second, existing surveys of port efficiencies have only been administered at a point in time or for a limited timeframe. Thus, there is almost no information on how port efficiencies evolve over time from these studies.

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[2] Besides studies based on country-level survey measures of foreign port efficiencies, the U.S. Army Corps (ACE) also conducts approximately ten-year surveys of all facility locations in U.S. ports, including information on depth, berthing distance to wharf, and railway connections. To our knowledge, no one has used these data to develop measures of port efficiency. A major difficulty would be aggregation of data across facilities/docks at a port since

An alternative methodology to measure port efficiencies, used by a number of studies is data envelopment analysis (DEA). This procedure uses data on inputs, outputs and production function theory to derive an estimate of the most efficient production frontier across a group of ports. This then allows a calculation of port efficiency based on deviations from this frontier. Examples include Roll and Hayuth (1993), Martinez-Budria et al. (1999), Tongzon (2001), and Estache et al. (2004).[3] Drawbacks of this approach include, first, functional form assumptions that may not be correct. In particular, these methods typically assume constant returns to scale, though econometric evidence from production function estimates discussed below typically find economies of scale. A second drawback is that these methodologies do not generate any measure of error by which to gauge statistical confidence and are quite susceptible to bias from outliers. A third drawback is relatively strong data requirements of both inputs and output that are consistently measured across sample ports and time periods in the sample. This is a likely reason that most DEA studies are quite limited in the scope of ports analyzed.

Another alternative is econometric estimation of production/cost functions for ports which is found in a more limited number of studies. Estache et al. (2002) is an example of such a study and provides a review of previous analyses using these methodologies. While econometric estimation provides standard errors for its port efficiency measures in order to judge confidence in such measures, these studies suffer from similar difficulties with data requirements, particularly measurement of labor, capital and other inputs. As a result, such studies in the previous literature focus on only a handful of ports at a time and none that we are aware of have focused on U.S. ports.

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no volume measures are given for each facility/dock. The surveys also occur infrequently which also gives little time series information on how the port facilities evolve over time.

[3] There is also a related literature on a similar methodology called Free Disposal Hull (FDH) and Wang et al. (2003) compares these methodologies in measuring container port production efficiencies.

In response to difficulties encountered by the previous literature, this paper provides an entirely new method of uncovering port efficiency measures using U.S. Census data on imports into U.S. port districts (hereinafter referred to as "ports"). This methodology is econometric-based, providing standard errors of our estimated port efficiency measures, and uses readily available and high-quality data to estimate port efficiencies across literally hundreds of ports over a lengthy number of years.

Our starting point is the information contained in the measure of "import charges" incurred by the goods in transit, as reported in the U.S. Census data. More specifically, the U.S. Census defines import charges as:

> "…the aggregate cost of all freight, insurance, and other charges (excluding U.S. import duties) incurred in bringing the merchandise from alongside the carrier at the port of exportation – in the country of exportation – and placing it alongside the carrier at the first port of entry in the United States."

These import charges consist of three primary components: 1) costs associated with loading the freight and disembarking from the foreign port, 2) costs connected with transportation between ports, and 3) costs associated with U.S. port arrival and unloading of the freight. Component 1 is directly related to the foreign port's efficiency, at least for the portion of the port services connected with loading freight and efficient disembarking of ships. There are undoubtedly other foreign port services and attributes that are not included in this import charges measure. However, to the extent that the efficiency of these non-included services is strongly correlated with the efficiency of the included services, component 1 of import charges should be a good measure of overall foreign port efficiency. In analogous fashion, U.S. port efficiencies are directly connected to component 3 of import charges. Component 2 costs, connected with transportation between ports, are identified with a few observable factors. Namely, ocean freight costs have been found to be highly correlated with distance, while insurance costs correlate with value per weight of the product (e.g., see Clark et al. (2004), pp. 8-9).

This study implements a simple statistical analysis to disentangle and separately identify the effect of these three components. Namely, a regression of import charges on distance measures, weight and value of the product, and other observables described in the next section, remove component 2 effects and leave components 1 and 3 in the error term along with random white noise. Identifying components 1 and 3 can be accomplished through the introduction of "fixed effects" for the U.S. and foreign ports. In particular, there are repeated shipments to many U.S. ports in a given year for a given product originating from the same foreign port, we can include a dummy variable (fixed effect) for each foreign port and uncover its underlying contribution to import charges. Likewise, with multiple observations for each U.S. port for a given year and a given product, a dummy variable (fixed effect) uncovers each U.S. port's underlying contribution to import charges. These port fixed effects provide measures of port efficiencies. That is, as a port's contribution to import charges (i.e., the costs of getting the products to the docks and unloaded) increases, costs increase, and, thus, will be inversely related to the port's efficiency.

Estimation of these measures of U.S. and foreign port efficiencies allow the construction of efficiency measures and a ranking of ports by efficiency. These estimates are then compared with the rankings with the main "survey-based" measures produced by the Global Competitiveness Report that offer rankings of foreign ports. These comparisons yield a statistical correlation that suggests the model is, indeed, picking up efficiencies for our sample's ports. As mentioned above, unlike previous studies, the approach also allows for a time series analysis of the data that allows dynamic measures and comparisons of efficiencies over time; i.e., from 1991 through 2003. We also show how our methodology allows estimation of efficiencies for a subset of shipments (e.g., containerized) or products.

The rest of the paper proceeds as follows. The next section provides details of our statistical methodology to uncover U.S. and foreign port efficiency and describes our data. The following section provides our results including new efficiency rankings of U.S. and foreign ports, comparison to previous rankings, and an analysis of changes in rankings over time.

## METHODOLOGY

Our statistical methodology follows Clark et al. (2004), with important modifications to uncover U.S. and foreign port fixed effects – the measures of U.S. and foreign port efficiencies. The model estimated is given by equation (1) and is based on a simple cost model of transporting goods:

$$IC_{ijkt} = \alpha + \beta_1 Dist_{ij} + \beta_2 Wgt_{ijkt} + \beta_3 Valwgt_{ijkt} + \beta_4 Cont_{ijkt} + \beta_5 Vol_{ijt} + \beta_6 Cont_{ijkt} \times Wgt_{ijkt} + \beta_7 Cont_{ijkt} \times Valwgt_{ijkt} + \beta_8 Im\_Imbal_{ij} + \beta_9 Ex\_Imbal_{ij} + \eta_i + \theta_j + \gamma_k + \tau_t + \varepsilon_{ijkt}. \quad (1)$$

$IC_{ijkt}$ represents import charges and is specified in logarithm form, where (i) indexes U.S. ports, (j) indexes foreign ports, (k) indexes 6-digit Harmonized System (HS) products, and (t) indexes year. $Dist_{ij}$ is the logarithm of nautical miles between port (i) and (j) and is expected to have a positive coefficient ($\beta_1$) as freight charges increase with distance transported. $Wgt_{ijkt}$ is the logarithm of weight for product (k) transported between ports (i) and (j) in year (t) and is expected to be directly correlated with freight costs and, thus, have a positive sign for $\beta_2$. $Valwgt_{ijkt}$ is the U.S. dollar value of the shipments divided by its weight in kilos in logarithm form. Holding weight constant, a higher value of the product per unit is expected to increase insurance costs, and thus, $\beta_3$ is expected to have a positive sign as well. $Cont_{ijkt}$ is the percent of shipments between port (i) and (j) for product (k) in year (t) that use container ships. Container shipments are expected to be a more efficient means of transportation, and therefore, $\beta_4$ should have a negative sign. $Vol_{ijt}$ is the total volume of trade in kilos across all products between port (i) and (j) for a given year (t) in logarithm form. Economies of scale arguments would suggest a negative sign for $\beta_5$, while congestion effects would suggest a positive sign. The next two terms are interactions of our containerization variable with weight and value per weight terms to allow for the possible variation in efficiencies from containerization depending on how heavy or valuable the product is. The following two terms are included to account for trade imbalances between foreign and U.S. port pairs, as import charges may be higher if a ship is more likely to travel empty in one of the directions. $Im\_Imbal_{ij}$ is the logarithm of the difference between imports and exports when this difference is positive and "0" otherwise. Similarly, $Ex\_Imbal_{ij}$ is the logarithm of the difference between exports and imports when this difference is positive and "0" otherwise. We expect $\beta_8$ and $\beta_9$ to be positive and identical unless traveling into a U.S. port empty is systematically more or less costly than traveling out of a U.S. port empty.

The final sets of estimated parameters are the model's fixed effects – sets of dummy variables. $\eta_i$ is the set of fixed-effects parameters that estimate the separate impact of each U.S. port on import charges holding all other factors constant. These represent the estimated measures of U.S. port efficiencies, with lower coefficients suggesting a more efficient port. In analogous fashion, $\theta_j$ are the foreign port fixed-effects parameters and identify foreign port efficiencies. $\gamma_k$ are product fixed-effects that control for other (unobserved) characteristics of products beyond value per weight that affect import charges differently across products. $\tau_t$ is a set of year effects that capture macroeconomic and technological shocks to import charges.

Finally, $\varepsilon_{ijkt}$ is assumed to be a random, white-noise error term. One effect is excluded from each set of fixed effects to avoid perfect multicollinearity with our constant term, $\alpha$.

It is important to stress what our fixed-effects measurements of port efficiency capture and how they may differ from other "efficiency" measures. Given how import charges are calculated, we are only capturing factors that affect the shipment costs that are connected with navigating the harbor and unloading the goods dockside. Efficiency of other port activities, particularly intermodal connections, are less likely to be captured. However, since import charges include port tariffs, we are also capturing any factors that affect these tariffs, such as port administration and financing efficiency. This begs the question why port tariffs are not an equally appropriate measure of efficiency. The answer is that such tariffs do not necessarily include costs associated with navigation of the harbor, tide restrictions, and other factors that can delay shipments into ports. We also note that such harbor and navigation costs do not factor into efficiency measures derived through DEA calculations of estimation of production or cost functions that only consider the use of dockside inputs (capital and labor typically) for the observed output. A port may be fully efficient once the ship is dockside, but a high-cost (hence, inefficient) port due to navigation difficulties, congestion, etc. This highlights another important advantage of our methodology.

The main difference with the specification employed in this paper and that employed in Clark et al. (2004) is the estimation of foreign port efficiencies with fixed effects. Clark et al. (2004) does not estimate these, but instead includes survey measures of foreign port efficiencies reported in the Global Competitiveness Report (various issues) -- henceforth, referred to as GCR measures -- as a regressor in their specification. In other words, the difference is that in the present study the import charge data reveal foreign port efficiencies, whereas Clark et al. (2004)

uses an external data source. There are two main strengths of the fixed effect model relative to the GCR measure of foreign port efficiencies. First, foreign port efficiencies are measured by year for as many years as the trade data exist, whereas the GCR measure is only reported beginning in 1995. Second, the GCR measure is only available for a limited set of countries (approximately 50), whereas we can estimate such measures for all foreign ports, not just countries. As in this study, Clark et al. (2004) includes U.S. port fixed effects in its specification. However, Clark et al. (2004) does not report these, nor do they make the link to using these as measures of U.S. ports' efficiencies.[4] Towards the end of the paper we compare our measurements of foreign port efficiencies with the GCR measures.

A final issue is the role of market power in determining import charges, either from ports or carriers. Estimation of the specification in (1) is based on a model of marginal costs of transporting merchandise and handling shipments. For example, as noted by Clark et al. (2004), it's possible that two different ports may have identical efficiencies, but one port charges more in fees due to greater market power. Clark et al. (2004) included measures of market power, including information on price-fixing agreements and cooperative agreements between ports and carriers, and found that they did not provide any significant explanatory information for import charges.[5] Finally, to the extent that "larger" ports have greater market power, our volume measure will control for market power effects.

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[4] On a more technical note, Clark et al. (2004) specifies their dependent variable as the logarithm of import charges *divided by the weight of the product.* The study also combines the value and weight regressors into one variable by taking the logarithm of the ratio of value to weight. An obvious statistical concern with this is that the value to weight regressor is endogenous with the dependent variable as they both contain the weight variable. For this reason, the present study does not use ratios of the variables.

[5] Sanchez et al. (2003) provided a similar analysis to Clark et al. (2004) focusing only on Latin American ports and also found no significant correlation between these proxies for market power and import charges.

## DATA

The data used in this analysis are from two sources both provided by the National Data Center (NDC) of the Army Corps of Engineers (ACE). ACE maintains public-use trade data comparable to the U.S. Census IA 245 files. These data are generated from Census files and matched to Customs vessel entrances/clearances for more complete and accurate vessel and U.S. port data. This data set is used to construct $IC_{ijkt}$, $Valwgt_{ijkt}$, $Cont_{ijkt}$, $Vol_{ij}$, $Im\_Imbal_{ij}$, $Ex\_Imbal_{ij}$, and related interaction terms over all the years available with the necessary data - 1991 through 2003.

ACE has also developed a preliminary databank containing port-to-port nautical miles. There are 375 different US ports in these data which connect to 1789 different domestic and foreign ports. This data set is used to construct the distance ($Dist_{ij}$) variable. Merging these distance data into the trade data was problematic since the files did not have common U.S. port codes. The authors developed a correspondence between the two datasets for these U.S. port codes in order to merge the data.

The combined database contains millions of observations, where the unit of observation is a U.S. port, foreign port, a six-digit HS product code and year. Such a large data set presents some computation difficulties. To mitigate this, we first limit our sample to the top 100 foreign ports by import volume which covers over 81% of all U.S. import activity. Second, we estimated our model for each year, rather than the full sample. Yearly samples had hundreds of thousands of observations and each required over 10 hours of computation time on a Linux machine with 8 Gigabytes of RAM using the statistical package, STATA.

## RESULTS AND PORT EFFICIENCY ESTIMATES

OLS is applied to equation (1) for each year of our sample, 1991 through 2003, and TABLE 1 provides our econometric results. Before focusing on the estimates for the port fixed effects (our measures of port efficiencies), a short discussion of the overall fit and efficacy of the model is provided.

The fit of the model to the data is quite high and stable across years, with $R^2$ statistics ranging from 0.90 to 0.92, indicating that our control variables explain 90% (or more) of the variation in import charges. F-statistics confirm the statistical significance for each of our sets of fixed effects at the 1% significance level.

In general, the control regressors separately listed in TABLE 1 have expected signs and conform to results from previous studies. Given these control regressors are in logarithm form, the coefficients on these regressors can be read as elasticities. Distance is positively correlated with import charges and its coefficient ranges from 0.1277 to 0.2123 over the sample years. Thus, these estimates suggest that a 10% increase in distance will increase import charges from 1.3 to 2.1%. This is consistent with previous studies in that there is not a one-to-one increase in import charges with distance. Weight and value per unit (VALWGT) are also positively correlated with import charges. Import charges increase almost one-to-one with weight, as indicated by a coefficient that averages around 0.91 over the sample years. The coefficient estimates on VALWGT suggest that a 10% increase in the value per kilo increases import charges by 5.5%. The volume measure displays an estimated positive correlation with import charges for all but one year and is typically statistically significant though very small in magnitude. This suggests that congestion effects of volume slightly outweigh the economies of scale effects. As expected, the effect of containerization, everything else equal, is a reduction in import charges, though the elasticity is fairly small, averaging about -0.05 over our sample years. The terms interacted with the containerization variable are also statistically significant, though small in magnitude as well. The positive coefficient on CONT×WGT suggests that the cost-reducing effects of containerization are mitigated for heavier products. On the other hand, the negative coefficient on CONT×VALWGT reveals that the cost-reducing impact of containerization is larger for products with higher value per unit. The final controls for which we list results in TABLE 1 are our trade imbalance measures which are typically not statistically significant. Clark et al. (2004), using alternative measure of trade imbalances, likewise finds no robust evidence that trade imbalances affect import charges in a significant manner.

## Estimated Port Efficiency Measures

### *U.S. Port Efficiencies Measures*

The model estimated for our results in Table 1 also includes sets of fixed effects for U.S. ports, foreign ports, and 6-digit HTS products. Each of these sets of fixed effects is jointly statistically different from zero at the 1% significance level in all regressions. Column 1 of TABLE 2 provides the average fixed-effect estimate for the top 50 (by volume) U.S. ports across all years in our sample and ranks them from most efficient to least efficient port. These port fixed effects coefficients provide estimates of a port's impact on import charges that are independent from other variables included in our regression. The inclusion of product fixed effects in our regression, for example, means that the port fixed effects should be free of bias from differences in the mix of products a port handles. The lower (or more negative) the coefficient, the lower the U.S. port's effects on import charges all other variables held constant and, thus, the more efficient the port.

To avoid perfect multicollinearity with our constant term, we dropped the Port of Oakland from the set of U.S. port fixed effects. Thus, the fixed-effects estimates in TABLE 2 are relative to the Port of Oakland's effect on import charges which is zero by construction. Given our dependent variable is in logarithm form, the coefficients in column 1 in TABLE 2 are approximately equal to the percentage difference (in decimal form) in the port's effect on import charges relative to the Port of Oakland effect, after controlling for all other factors. For example, a coefficient of -0.02 indicates that the component of import charges connected with that port is roughly 2% less than the same port costs in the Port of Oakland for a shipment of the same product from a foreign port that is the same distance away. To get the percentage difference in efficiency from Oakland, one simply takes the difference in the exponent of the fixed effect coefficient minus one and multiplies by 100.[6] Statistical confidence of the fixed-effects estimates for our top 50 ports all average greater than 95% over our sample years.

An examination of the U.S. port fixed effects estimates reveals that many of the Gulf Coast and West Coast ports rank in the upper half of the list, with Gulfport, Mississippi topping the list with a coefficient of -0.087, indicating import charges average roughly 8% less than the Port of Oakland. The island ports of Honolulu, Hawaii and San Juan are essentially outliers at the bottom of the list in terms of efficiency with coefficients of 0.349 and 0.609, respectively. Overall, there is a significant range of estimated port efficiencies. Only 15 of the 50 ports are within 0.05 of the Port of Oakland; that is, within roughly 5% of the Port of Oakland's impact on import charges. The average port has a fixed effect around 0.08 with a standard deviation for the sample around 0.11.

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[6] This percentage will be quite close to the fixed effect coefficient (in decimal) form when the coefficients are close to zero, as is true of many of our estimated coefficients.

We note that precision of our estimates for port efficiencies of ports smaller than the top 50 are generally quite weak and it is difficult to have much confidence in our estimates for these ports. However, the top 50 ports account for over 97% of all import volume into the U.S., so our methodology obtains significant results for virtually all U.S. import activity.

As indicated throughout this paper, an important feature of this study's new method of estimating port efficiencies is the ability to derive such estimates for each port over time – not just a cross-sectional comparison. As an example of the benefit of this time series element, Column 3 of TABLE 2 provides the change in the U.S. port's fixed effect coefficient over the sample years relative to the Port of Oakland's effect on import charges. These come from subtracting the port's average fixed effect for the initial three years of 1991 through 1993 from the port's average fixed effect from the final three years of the sample, 2001 through 2003. A negative coefficient indicates that the port became more efficient relative to the Port of Oakland over this period, whereas a positive coefficient indicates that it became less efficient.

There is a wide variation in ports' efficiency changes over this time period, with the average experience being a loss in efficiency of 0.06 relative to the Port of Oakland; in other words, everything else equal, an import shipment to the average port cost roughly 6% more in import charges relative to Oakland in the early 2000s than in it did in the early 1990s. One other pattern to note is that Gulf of Mexico ports consistently gained in efficiency relative to Oakland over this period, whereas East coast ports, generally lost ground.

To get a more detailed view of time series changes, FIGURES 1, 2 and 3 plot out port efficiency coefficients (relative to Oakland) on an annual basis for certain select ports. FIGURE 1 plots West Coast ports, FIGURE 2 plots Gulf of Mexico ports, and FIGURE 3 plots East Coast ports. FIGURE 1 shows that other West Coast ports generally lost ground to the Port of Oakland in terms of efficiency over our sample period. One can also observe that the Port of Long Beach lost some efficiency relative to the other ports during this period as well. Gulf Coast ports displayed in FIGURE 2 show a fair amount of variation in efficiency over the sample period, though their efficiencies by the end of the period are very similar to the first year of the sample. Houston and New Orleans have similar efficiency measures over time, while the Port of Mobile is slightly less efficient, particularly over the late 1990s and early 2000s. The East Coast ports displayed in FIGURE 3 show the largest changes in relative efficiency rankings over time. In particular, the Port of Norfolk goes from the most efficient of the group to the least efficient over time, while Port Everglades goes from the least efficient of the group in 1991 to one of the more efficient by 2003.

### *Foreign Port Efficiencies Measures*

Analogous to the estimated U.S. port fixed effects, the estimated foreign port fixed effects provide measures of foreign port efficiencies, where the smaller (or more negative) the coefficient, the more efficient the port relative to the port we exclude from our foreign port set – Rotterdam, the Netherlands. Column 1 of TABLE 3 provides our estimates of foreign port fixed effects from the OLS results using our entire sample and ranks them from most efficient to least efficient port. Column 2 of TABLE 3 lists the foreign port's market share of total U.S. imports, while column 3 of TABLE 3 provides the change in the foreign port's fixed effect coefficient from the early 1990s to the early 2000s relative to the Port of Rotterdam's effect on import charges.

A number of obvious patterns emerge in the rankings of the foreign ports. The upper half of the list (the most-efficient ports) is primarily European and Japanese ports. The middle of the list is generally populated by newly-industrialized countries in Southeast Asia, such as Taiwan and Korea, while the least-efficient ports are primarily Central American and Chinese ports. As with the U.S. port efficiency measures, most are estimated to be statistically different from zero – the efficiency of the Rotterdam port by construction – at the 5% significance level or better.

Column 3 of TABLE 3 shows how estimated port efficiency measures changed over our sample period. As with the U.S. port data, we calculate this as the average port efficiency from 2001 through 2003 minus the average port efficiency from 1991 through 1993. There is substantial variation in port efficiency changes over the sample with a standard deviation of 0.16, but the average change in port efficiency relative to Rotterdam is -0.05, or a 5% efficiency gain.

### *Comparing Our Foreign Port Efficiency Measures to the GCR Measures*

As mentioned, previous literature has used the GCR measures as proxies for foreign port efficiency. While these measures are only available for certain countries, one can examine how comparable this study's measures are to the GCR measures by aggregating our port measures by country (using our import market shares as weights) and calculating a pairwise correlation. Clark et al. (2004) reports and uses the GCR measures for the year 1998. An average country-level port efficiency measure for the 1997-1999 period using this study's estimated port efficiencies is constructed, which yields 29 matches with the GCR data. The pairwise correlation is 0.33 between the two measures and is statistically significant at the 7% confidence level.

Interestingly, the two contiguous countries to the U.S. yield unexpected port efficiencies measures using our methodology, with Canada's ports ranking as some of the worst and Mexico's ports ranking as some of the best in the world. Our current control regressors may not be adequately capturing these countries special geography with the U.S. If we discard these two observations, the correlation between this study's estimated measures of port efficiencies and the GCR measures is 0.65 and statistically significant at the 1% confidence level. This suggests that our study's measures are capturing similar port efficiency effects to the GCR measures (with the exception of contiguous countries). However, this paper's methodology can provide such port efficiency measures for many more years than the GCR data and for conceivably all foreign ports (not just countries) from which the U.S. imports.

### *U.S. Port Efficiencies for Select Products: Steel and Autos*

Another significant advantage of the methodology in this paper is our ability to easily estimate port efficiencies for only a subset of products. This is done by simply re-estimating the model represented in equation (1) for only observations on the products of interest. For example, TABLES 4 and 5 provide information on U.S. port efficiencies estimated when focusing on only steel products or autos, respectively, using data for the year 1999. For both products, the port efficiencies are again measured relative to the Port of Oakland, which is a significant port for both types of imported products. Panel A of each table displays ports with at least a 1% market share in the product and which are significantly different than Oakland in terms of efficiency, while Panel B of each table displays other ports with at least 1% market share that are not statistically different than Oakland in terms of efficiency. Our estimates reported in TABLE 4 suggest that both the Ports of Tampa and Baton Rouge are significantly more efficient for handling steel products, while Los Angeles, Chester, Camden, and San Juan are ports with significant market shares, but less efficient than Oakland in handling these products. In autos (TABLE 5), the Port of Brunswick, Georgia is estimated to be significantly more efficient than all other ports, while Long Beach, Norfolk, Charleston, Tacoma, New York & New Jersey, and Boston are estimated to be significantly inefficient relative to Oakland.

## CONCLUSION

This study provides new measures of ocean port efficiencies through simple statistical tools using U.S. data on import flows from 1991 through 2003. Unlike previous measures using surveys, DEA, or production/cost function estimation, this study's methodology can provide such estimates for a much broader sample of countries and years with little cost. It also has the flexibility to quickly provide port efficiency comparisons on a commodity-by-commodity basis (e.g., which U.S. ports are more efficient at handling steel products). The costliness and strong data requirements of other methodologies is likely why MARAD was unable to identify or provide any port efficiency comparison in a recent Congressional request. Beyond the important role of informing policy makers, the readily-available measures of port efficiency can used by future researchers to examine a myriad of new issues, including the evolution of port efficiencies over time and its effects on international trade flows and country-level growth.

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## TABLE 1: OLS Estimates of Determinants of Import Charges for U.S. Imports, 1991-2003.

| | Dependent Variable: Import Charges | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Regressors** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** |
| **DIST** | **0.1643*** | **0.1785*** | **0.1883*** | **0.1978*** | **0.1573*** | **0.1508*** | **0.1892*** | **0.1967*** | **0.1710*** | **0.2123*** | **0.2106*** | **0.1893*** | **0.1277*** |
| | (0.0050) | (0.0052) | (0.0052) | (0.0052) | (0.0052) | (0.0050) | (0.0050) | (0.0049) | (0.0054) | (0.0053) | (0.0057) | (0.0052) | (0.0050) |
| **WGT** | **0.9046*** | **0.9103*** | **0.9141*** | **0.9124*** | **0.9121*** | **0.9156*** | **0.9161*** | **0.9088*** | **0.9143*** | **0.9046*** | **0.9013*** | **0.9053*** | **0.8953*** |
| | (0.0024) | (0.0028) | (0.0026) | (0.0021) | (0.0022) | (0.0016) | (0.0018) | (0.0020) | (0.0023) | (0.0023) | (0.0025) | (0.0023) | (0.0024) |
| **VALWGT** | **0.5550*** | **0.5818*** | **0.5718*** | **0.5267*** | **0.5326*** | **0.5276*** | **0.5466*** | **0.5498*** | **0.5540*** | **0.5335*** | **0.5377*** | **0.5465*** | **0.5381*** |
| | (0.0045) | (0.0052) | (0.0051) | (0.0039) | (0.0044) | (0.0030) | (0.0034) | (0.0039) | (0.0044) | (0.0045) | (0.0048) | (0.0046) | (0.0047) |
| **CONT** | **-0.0454*** | **-0.0489*** | **-0.0365*** | **-0.0466*** | **-0.0465*** | **-0.0334*** | **-0.0352*** | **-0.0466*** | **-0.0318*** | **-0.0551*** | **-0.0607*** | **-0.0568*** | **-0.0693*** |
| | (0.0059) | (0.0069) | (0.0065) | (0.0051) | (0.0056) | (0.0040) | (0.0046) | (0.0051) | (0.0058) | (0.0058) | (0.0063) | (0.0059) | (0.0061) |
| **VOL** | **0.0073*** | **0.0055*** | **0.0059*** | **0.0063*** | **0.0057*** | **0.0020** | **0.0068*** | **0.0041*** | **0.0039*** | **0.0096*** | **0.0009** | **0.0055*** | **-0.0008*** |
| | (0.0015) | (0.0017) | (0.0015) | (0.0015) | (0.0015) | (0.0014) | (0.0015) | (0.0015) | (0.0017) | (0.0016) | (0.0017) | (0.0016) | (0.0016) |
| **CONT*WGT** | **0.0068*** | **0.0064*** | **0.0060*** | **0.0068*** | **0.0070*** | **0.0053*** | **0.0054*** | **0.0069*** | **0.0066*** | **0.0088*** | **0.0089*** | **0.0083*** | **0.0107*** |
| | (0.0005) | (0.0006) | (0.0006) | (0.0005) | (0.0005) | (0.0004) | (0.0004) | (0.0005) | (0.0005) | (0.0005) | (0.0006) | (0.0005) | (0.0005) |
| **CONT*VALWGT** | **-0.0040*** | **-0.0044*** | **-0.0074*** | **-0.0036*** | **-0.0041*** | **-0.0029*** | **-0.0047*** | **-0.0083*** | **-0.0118*** | **-0.0103*** | **-0.0118*** | **-0.0119*** | **-0.0095*** |
| | (0.0010) | (0.0011) | (0.0011) | (0.0009) | (0.0010) | (0.0007) | (0.0008) | (0.0009) | (0.0010) | (0.0010) | (0.0011) | (0.0010) | (0.0010) |
| **IM_IMBAL** | **-0.0003** | **0.0016** | **-0.0010** | **0.0014** | **-0.0048*** | **-0.0008** | **-0.0039*** | **-0.0003** | **-0.0014** | **-0.0028*** | **0.0008** | **-0.0021*** | **0.0020*** |
| | (0.0009) | (0.0010) | (0.0010) | (0.0010) | (0.0010) | (0.0008) | (0.0010) | (0.0010) | (0.0012) | (0.0010) | (0.0011) | (0.0010) | (0.0009) |
| **EX_IMBAL** | **-0.0006** | **0.0008** | **-0.0012** | **0.0013** | **-0.0052*** | **-0.0006** | **-0.0042*** | **-0.0010** | **-0.0017** | **-0.0031*** | **0.0004** | **-0.0031*** | **0.0008** |
| | (0.0009) | (0.0010) | (0.0010) | (0.0010) | (0.0009) | (0.0008) | (0.0009) | (0.0010) | (0.0011) | (0.0010) | (0.0010) | (0.0009) | (0.0009) |
| Number of Observations | 337677 | 343131 | 371185 | 379158 | 382293 | 456418 | 465566 | 521467 | 437691 | 473245 | 442076 | 483595 | 549804 |
| R-Squared | 92 | 92 | 92 | 92 | 92 | 91 | 91 | 91 | 91 | 91 | 90 | 91 | 90 |
| F-Statistic | 748 | 756 | 823 | 893 | 891 | 942 | 943 | 1024 | 857 | 923 | 817 | 917 | 1009 |

*Notes: All variables are logged. A constant intercept term was included, as well as U.S. port fixed effects, foreign port fixed effects, and 6-digit HTS product fixed effects. * indicates significance at the 1% level.*

### TABLE 2: U.S. Port Efficiencies

| Port Name | Port Fixed Effects: Efficiencies Relative to Oakland | Port's Market Share of U.S. Import Volume Over Sample Years (percent) | Change in Port Efficiency Relative to Oakland from 1991-1993 Period to 2001-2003 Period |
|---|---|---|---|
| Gulfport, MS | -0.087 | 0.22 | -0.028 |
| Port Hueneme, CA | -0.087 | 0.77 | 0.206 |
| San Francisco, CA | -0.082 | 0.27 | 0.119 |
| Pascagoula, MS | -0.082 | 0.43 | -0.099 |
| Port Huron, MI | -0.046 | 0.34 | 0.147 |
| Freeport, TX | -0.028 | 0.54 | 0.114 |
| Baton Rouge, LA | -0.018 | 0.68 | -0.083 |
| Oakland, CA | 0.000 | 3.82 | 0.000 |
| Galveston, TX | 0.022 | 0.31 | -0.012 |
| New Haven, CT | 0.023 | 0.17 | 0.233 |
| Gramercy, LA | 0.024 | 0.17 | NA |
| Portland, OR | 0.026 | 1.42 | 0.015 |
| Chester, PA | 0.030 | 0.46 | 0.060 |
| Lake Charles, LA | 0.035 | 0.65 | -0.435 |
| Newport News, VA | 0.038 | 0.33 | 0.129 |
| Beaumont, TX | 0.039 | 0.96 | 0.203 |
| Long Beach, CA | 0.045 | 14.91 | 0.080 |
| Boston, MA | 0.048 | 0.71 | 0.073 |
| Corpus Christi, TX | 0.048 | 1.21 | 0.284 |
| Norfolk, VA | 0.051 | 2.82 | 0.131 |
| Los Angeles, CA | 0.051 | 15.96 | 0.043 |
| Houston, TX | 0.054 | 4.08 | 0.018 |
| Savannah, GA | 0.064 | 2.04 | 0.074 |
| Mobile, AL | 0.066 | 0.39 | 0.074 |
| Charleston, SC | 0.069 | 3.64 | 0.067 |
| Jacksonville, FL | 0.071 | 1.67 | -0.070 |
| Philadelphia, PA | 0.072 | 1.60 | -0.051 |
| Brunswick, GA | 0.072 | 0.53 | -0.291 |
| Wilmington, NC | 0.073 | 0.31 | 0.160 |
| Baltimore, MD | 0.079 | 3.18 | -0.021 |
| New Orleans, LA | 0.080 | 1.92 | 0.053 |
| NY & NJ | 0.091 | 12.07 | 0.022 |
| Providence, RI | 0.095 | 0.21 | -0.203 |
| St. Croix, VI | 0.104 | 0.70 | 0.023 |
| Port Everglades, FL | 0.114 | 1.01 | -0.088 |

| | | | |
|---|---|---|---|
| Detroit, MI | 0.116 | 0.32 | -0.054 |
| Miami, FL | 0.123 | 1.59 | -0.014 |
| Texas City, TX | 0.130 | 0.69 | 0.263 |
| Seattle, WA | 0.145 | 5.32 | 0.027 |
| Paulsboro, NJ | 0.145 | 0.42 | 0.707 |
| Tacoma, WA | 0.152 | 3.62 | 0.021 |
| Richmond, CA | 0.155 | 0.27 | 0.524 |
| Tampa, FL | 0.169 | 0.19 | 0.074 |
| Marcus Hook, PA | 0.175 | 0.20 | 0.793 |
| Wilmington, DE | 0.182 | 0.65 | -0.001 |
| San Diego, CA | 0.190 | 0.51 | -0.027 |
| Port Arthur, TX | 0.218 | 0.71 | 0.053 |
| Morgan City, LA | 0.230 | 0.86 | -0.246 |
| San Juan, PR | 0.349 | 0.68 | 0.038 |
| Honolulu, HI | 0.609 | 0.29 | 0.133 |

*Notes: "NA" indicates that this figure is not available for this port, since it did not have an estimated port fixed effect for one of the years.*

## TABLE 3: Foreign Port Efficiencies

| Port Name | Port Fixed Effects: Efficiencies Relative to Rotterdam | Port's Market Share of U.S. Import Volume, 1991- 2003 (percent) | Change in Port Efficiency Relative to Rotterdam from 1991-1993 Period to 2001-2003 Period |
|---|---|---|---|
| Dos Bocas, Mexico | -0.252 | 0.36 | -0.254 |
| Forcados, Nigeria | -0.175 | 0.26 | NA |
| Zeebrugge, Belgium | -0.053 | 0.19 | -0.479 |
| Shimizu, Japan | -0.050 | 0.63 | -0.109 |
| Chiba, Japan | -0.031 | 0.58 | 0.171 |
| Bremerhaven, Germany | -0.017 | 4.03 | -0.027 |
| Antwerp, Belgium | -0.015 | 2.32 | 0.060 |
| Osaka, Japan | -0.010 | 0.98 | 0.099 |
| Rotterdam, Netherlands | 0.000 | 2.24 | 0.000 |
| Chi Lung, Taiwan | 0.013 | 1.93 | -0.001 |
| Escravos Oil Terminal, Nigeria | 0.014 | 0.22 | NA |
| Le Havre, France | 0.017 | 1.18 | -0.005 |
| Hamburg, Germany | 0.018 | 0.53 | -0.034 |
| Kawasaki, Japan | 0.019 | 0.21 | 0.162 |
| Hakata, Japan | 0.023 | 0.26 | 0.160 |
| Bremen, Germany | 0.026 | 0.64 | 0.008 |
| Fos, France | 0.035 | 0.18 | -0.094 |
| Pajaritos, Mexico | 0.046 | 0.59 | -0.594 |
| Nagoya, Japan | 0.052 | 3.27 | -0.065 |
| Southhampton, United Kingdom | 0.053 | 0.69 | -0.007 |
| Puerto Plata, Dominican Republic | 0.057 | 0.17 | -0.166 |
| Tai Chung, Taiwan | 0.061 | 0.25 | 0.054 |
| Emden, Germany | 0.064 | 0.67 | -0.203 |
| Kao Hsiung, Taiwan | 0.066 | 2.54 | -0.018 |
| Liverpool, United Kingdom | 0.066 | 0.4 | -0.072 |
| All Other Colombian/Caribbean Ports | 0.068 | 0.36 | 0.063 |
| Haifa, Israel | 0.069 | 0.31 | -0.176 |
| Kobe, Japan | 0.077 | 2.21 | -0.022 |
| Felixstowe, United Kingdom | 0.080 | 1.01 | -0.074 |
| Tokyo, Japan | 0.083 | 4.21 | -0.067 |
| Toyohashi, Japan | 0.084 | 2.52 | -0.260 |
| Rio Grande, Brazil | 0.090 | 0.22 | -0.105 |
| Goteborg, Sweden | 0.096 | 0.72 | -0.068 |
| Yokohama, Japan | 0.100 | 2.78 | 0.039 |

| | | | |
|---|---|---|---|
| Inchon, South Korea | 0.101 | 0.22 | 0.125 |
| All Other South Korea Ports | 0.107 | 0.27 | 0.084 |
| Pusan, South Korea | 0.108 | 2.74 | 0.026 |
| Sarnia (Ont), Canada | 0.109 | 0.35 | NA |
| Amuay Bay, Venezuela | 0.112 | 0.38 | -0.096 |
| Hong Kong, Hong Kong | 0.113 | 9.31 | 0.004 |
| Kwa Ibo Termina, Nigeria | 0.117 | 0.32 | NA |
| Rio Haina, Dominican Republic | 0.125 | 0.26 | -0.101 |
| Sullom Voe, United Kingdom | 0.126 | 0.21 | NA |
| Yokosuka, Japan | 0.127 | 0.91 | -0.026 |
| Mizushima, Japan | 0.127 | 0.17 | 0.114 |
| All Other Venezuelan Ports | 0.133 | 0.61 | -0.109 |
| Yokkaichi, Japan | 0.136 | 0.39 | 0.255 |
| Buenos Aires, Argentina | 0.137 | 0.21 | -0.250 |
| Singapore, Singapore | 0.141 | 1.65 | -0.008 |
| Puerto La Cruz, Venezuela | 0.142 | 0.67 | 0.268 |
| La Spezia, Italy | 0.144 | 0.56 | -0.105 |
| Penang, Malaysia | 0.144 | 0.49 | -0.039 |
| Genoa, Italy | 0.147 | 0.5 | -0.056 |
| All Other Thai Ports | 0.149 | 0.23 | 0.034 |
| Jahore, Malaysia | 0.153 | 0.2 | -0.024 |
| Durban, South Africa | 0.154 | 0.23 | 0.012 |
| All Other Japan Ports | 0.158 | 0.66 | 0.222 |
| Melbourne, Australia | 0.160 | 0.22 | -0.252 |
| Mongstad, Norway | 0.166 | 0.22 | NA |
| Limon, Costa Rica | 0.166 | 0.31 | -0.140 |
| La Salina, Venezuela | 0.169 | 0.25 | -0.045 |
| Karachi, Pakistan | 0.171 | 0.28 | -0.102 |
| Rio de Janeiro, Brazil | 0.174 | 0.19 | -0.164 |
| Leghorn, Italy | 0.179 | 0.54 | -0.093 |
| Puerto Cortes, Honduras | 0.185 | 0.44 | -0.024 |
| Valencia, Spain | 0.190 | 0.19 | -0.154 |
| Kelang, Malaysia | 0.192 | 0.4 | -0.071 |
| Sao Paulo, Brazil | 0.193 | 0.64 | -0.221 |
| Laem Chabang, Thailand | 0.193 | 0.42 | NA |
| Bangkok, Thailand | 0.195 | 0.96 | -0.016 |
| All Other Malaysia Ports | 0.202 | 0.32 | -0.148 |
| Ras Tanura, Saudia Arabia | 0.204 | 1.09 | -0.165 |
| Saint John (NB), Canada | 0.213 | 0.27 | NA |
| Onsan, South Korea | 0.217 | 0.32 | 0.265 |
| Al Fuhayhil, Kuwait | 0.218 | 0.17 | -0.259 |

| | | | |
|---|---|---|---|
| Colombo, Sri Lanka | 0.225 | 0.28 | -0.102 |
| Veracruz, Mexico | 0.228 | 0.31 | -0.195 |
| All Other China Ports | 0.234 | 0.98 | -0.024 |
| Jakarta, Indonesia | 0.238 | 0.64 | -0.074 |
| Yantian, China | 0.242 | 1.84 | 0.026 |
| All Other Indonesia Ports | 0.252 | 0.19 | -0.020 |
| Bombay, India | 0.253 | 0.29 | -0.203 |
| Ching Tao, China | 0.255 | 0.33 | -0.103 |
| St. Petersburg, Russia | 0.259 | 0.3 | -0.434 |
| Al Bakir, Iraq | 0.259 | 0.35 | NA |
| Shanghai, China | 0.267 | 2.04 | -0.156 |
| Dagu/Tanggu, China | 0.268 | 0.3 | -0.128 |
| Dalian, China | 0.270 | 0.21 | -0.151 |
| Santo Tomas de Castillo, Guatemala | 0.272 | 0.43 | -0.121 |
| Chittagong, Bangladesh | 0.287 | 0.27 | -0.076 |
| Hiroshima, Japan | 0.301 | 0.39 | 0.301 |
| Duran, Ecuador | 0.301 | 0.2 | -0.190 |
| Manilla, Philippines | 0.316 | 0.7 | -0.030 |
| Arzew, Algeria | 0.347 | 0.23 | 0.483 |
| High Seas, Gulf of Mexico | 0.353 | 1.05 | -0.109 |
| Puerta Miranda, Venezuela | 0.470 | 0.21 | -0.022 |
| Windsor (Ont), Canada | 0.512 | 0.18 | 0.141 |
| Bonny, Nigeria | 0.580 | 0.22 | NA |
| Point Tupper (CBI), Canada | NA | 0.17 | NA |
| Cayo Arcos, Mexico | NA | 0.65 | NA |

*Notes: "NA" indicates that this figure is not available for this port, since it did not have an estimated port fixed effect for one of the years.*

## TABLE 4: Port Efficiencies for U.S. Ports That Handle at Least 1% of US Imported Steel, 1999

**PANEL A: Ports With Significantly Different Efficiencies in Handling Steel Products Than the Port of Oakland**

| Port Name | U.S. Import Market Share in Steel Products | Port (Fixed Effects) Efficiencies |
|---|---|---|
| Tampa, FL | 1.21 | -0.439 |
| Baton Rouge, LA | 4.91 | -0.249 |
| Los Angeles, CA | 9.47 | 0.073 |
| Chester, PA | 1.09 | 0.112 |
| Camden, NJ | 1.75 | 0.151 |
| San Juan, PR | 1.91 | 0.251 |

**PANEL B: Ports With No Significantly Different Efficiencies in Handling Steel Products Than the Port of Oakland**

| Port Name | U.S. Import Market Share in Steel Products |
|---|---|
| New Orleans, LA | 22.86 |
| Houston, TX | 8.29 |
| Philadelphia, PA | 5.94 |
| Long Beach, CA | 4.80 |
| Detroit, MI | 4.51 |
| Chicago, IL | 3.96 |
| Baltimore, MD | 3.50 |
| Savannah, GA | 3.44 |
| NY & NJ | 2.31 |
| Mobile, AL | 1.60 |
| New Haven, CT | 1.59 |
| Cleveland, OH | 1.50 |

## TABLE 5: Port Efficiencies for U.S. Ports That Handle at Least 1% of US Imported Autos, 1999

**PANEL A: Ports With Significantly Different Efficiencies in Handling Autos Than the Port of Oakland**

| Port Name | U.S. Import Market Share in Autos | Port (Fixed Effect) Efficiency |
|---|---|---|
| Brunswick, GA | 2.95 | -0.271 |
| Long Beach, CA | 11.29 | 0.090 |
| Norfolk, VA | 3.96 | 0.106 |
| Charleston, SC | 3.67 | 0.111 |
| Tacoma, WA | 3.73 | 0.117 |
| NY & NJ | 13.00 | 0.153 |
| Boston, MA | 1.83 | 0.428 |

**PANEL B: Ports With No Significantly Different Efficiencies in Handling Autos Than the Port of Oakland**

| Port Name | U.S. Import Market Share in Autos |
|---|---|
| Los Angeles, CA | 14.35 |
| Jacksonville, FL | 7.39 |
| Baltimore, MD | 6.49 |
| Portland, OR | 6.27 |
| Seattle, WA | 5.11 |
| Port Hueneme, CA | 3.98 |
| San Diego, CA | 3.50 |
| Houston, TX | 2.14 |
| Wilmington, DE | 1.77 |
| Vancouver, WA | 1.06 |

**FIGURE 1: West Coast Ports' Efficiencies Relative to Oakland, 1991-2003**

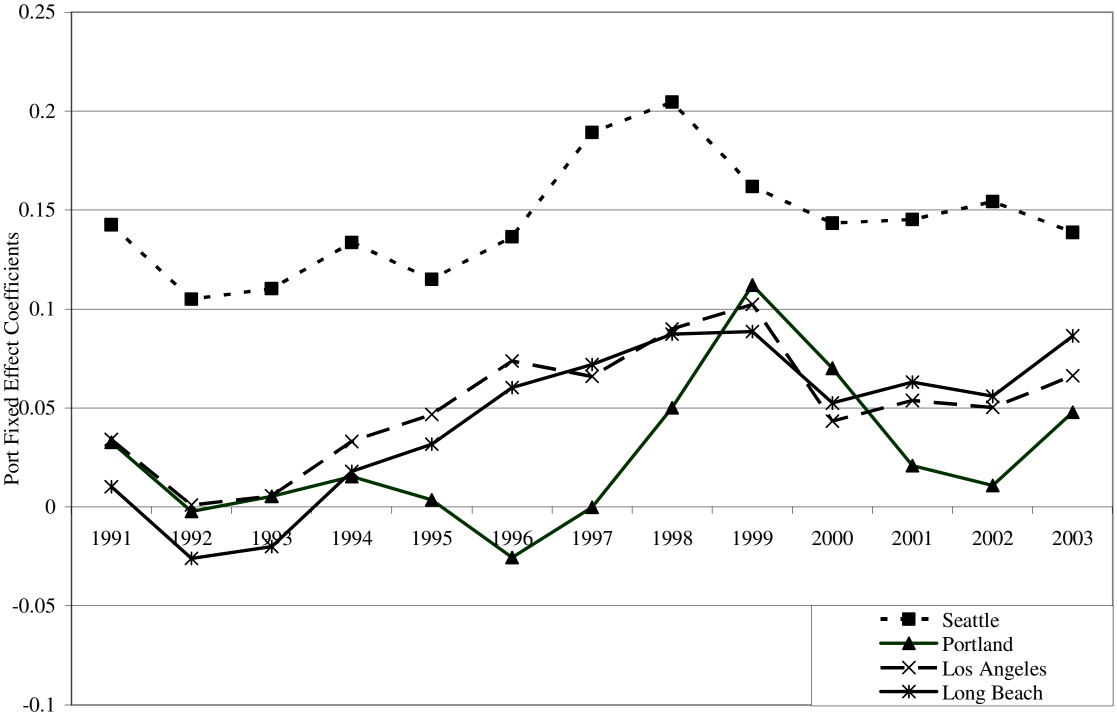

**FIGURE 2: Gulf of Mexico Ports' Efficiencies Relative to Oakland, 1991-2003**

**FIGURE 3: East Coast Ports' Efficiencies Relative to Oakland, 1991-2003**