Review of International Economics, 16(1), 21–36, 2008
DOI:10.1111/j.1467-9396.2007.00723.x

Port Efficiency and Trade Flows*

Bruce A. Blonigen and Wesley W. Wilson

Abstract

Growing international trade and increasing congestion focus attention on trade facilitation. Ocean ports are a central and necessary component in facilitating trade. Yet, there is only limited comprehensive information available on the efficiency of ports or evidence of the effect of port efficiency on trade. We develop and apply a straightforward approach to estimate port efficiency. The approach uses detailed data on US imports and associated import costs, yielding estimates across ports, products, and time. These measures are incorporated into a gravity trade model where we estimate that improved port efficiency significantly increases trade volumes.

1. 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 may reduce trade volumes, particularly for small, less-developed countries (Wilson et al., 2003; Clark et al., 2004).[1] Thus, port efficiency is an important issue in addressing trade facilitation practices, which has been a recent focus of the World Trade Organization and regional trade institutions, such as the Asia-Pacific Economic Cooperation organization. Disruptions to US 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).

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, consistent data and methods to construct measures and allow comparisons across ports are not currently available even in developed countries. As stated in a recent report to Congress by the US 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

---

* Blonigen: National Bureau of Economic Research; Department of Economics, University of Oregon, Eugene, OR 97403, USA. Tel: 541-346-4680; Fax: 541-346-1243; E-mail: bruceb@uoregon.edu. Wilson: Institute for Water Resources; Department of Economics, University of Oregon, Eugene, OR 97403, USA. Tel: 541-346-4690; Fax: 541-346-1243; E-mail: wwilson@uoregon.edu. This research has been conducted under and supported by the Navigation Economics Technologies (NETS) program at the Institute for Water Resources at the US Army Corps of Engineers. The research was facilitated by the efforts of Douglas MacDonald, discussions with Susan Hassett and David Hummels, and excellent comments by an anonymous referee, Keith Hofseth, Bruce Lambert, and other participants of the January 2006 NETS symposium in Salt Lake City, Utah. Any remaining errors are ours.

> would require the creation of new methodologies and the collection of data that were not available for this report."
> (US Department of Transportation, Maritime Administration, 2005, p. 8)[2]

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.

As concluded by MARAD and others (described in the next section), analyses of port efficiencies do not provide comprehensive measures across ports, products, or time, much less tie such measures to trade flows. This paper provides a new method for uncovering measures of port efficiency. The methodology uses readily available US Census data on imports into US port districts (hereinafter referred to as "ports"). It is econometric-based and, hence, provides standard errors for the estimated port efficiency measures. Not only are the data readily available and of high quality, but they also allow the estimation of port efficiencies across literally hundreds of ports and over relatively lengthy time periods.

While there are many applications of this method and the resulting port efficiency measures, we focus on using our measures to examine the relationship between port efficiency and international trade flows in a standard gravity-trade specification. Wilson et al. (2003) and Clark et al. (2004) estimate this relationship using survey measures of port efficiency drawn from the *Global Competitiveness Report*.[3] A potential drawback of these studies is that the survey measures are for only a point in time and may proxy other unobserved country characteristics. In contrast, our port efficiency measures are time-varying, allowing controls for unobserved country-level heterogeneity in trade flows. We find that port efficiency is quite important in explaining trade flows between countries with a statistically significant elasticity of 0.4 after controlling for unobserved country-level heterogeneity. While significant, this is much lower than the elasticity we estimate when excluding country-level fixed effects; this suggests that previous studies may be overstating the impact of port efficiency on trade.

The rest of the paper proceeds as follows. After briefly reviewing related previous literature in the next section, we provide details of our statistical methodology to uncover US and foreign port efficiency in section 3. Section 4 describes our data, while section 5 provides the paper's statistical results of new efficiency rankings of US and foreign ports, as well as gravity-model estimates of the effect of port efficiency on international trade flows.

2. Previous Literature

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* published by the World Economic Forum. 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 that the firm strongly agrees with the statement. Drawbacks of survey data are, first, that 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. Secondly, existing surveys of port efficiencies have only been administered at a point in time or for a limited time frame. Thus, there is almost no information on how port efficiencies evolve over time from these studies.[4]

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. Port efficiency measures are then based on deviations from this frontier. Examples include Roll and Hayuth (1993), Martinez-Budria et al. (1999), Tongzon (2001), and Estache et al. (2004).[5] 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.

3. Methodology

Our conceptual starting point for estimating port efficiencies is the information contained in the measure of "import charges" incurred by the goods in transit, as reported in the US Census data. More specifically, the US 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 US 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, US 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).

Given this breakdown of components comprising import charges, 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. This leaves components 1 and 3 in the error term along with assumed random white noise. Identifying components 1 and 3 can be accomplished through the introduction of "fixed effects" for the US and foreign ports. In particular, there are repeated shipments to many US 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 US port for a given year and a given product, a dummy variable (fixed effect) uncovers each US 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.

More formally, our statistical methodology primarily follows Clark et al. (2004), with important modifications to uncover US and foreign port fixed effects—the measures of US and foreign port efficiencies.[6] The model estimated is given by equation (1) and is based on a simple cost model of transporting goods:

$$\begin{aligned} IC_{ijkt} = {} & \alpha + \beta_1 Dist_{ij} + \beta_2 Wgt_{ijkt} + \beta_3 Valwgt_{ijkt} + \beta_4 Cont_{ijkt} + \beta_5 Cont_{ijkt} \times Wgt_{ijkt} \\ & + \beta_6 Cont_{ijkt} \times Valwgt_{ijkt} + \beta_7 Im\_Imbal_{ij} + \beta_8 Ex\_Imbal_{ij} \\ & + \eta_i + \theta_j + \gamma_k + \tau_t + \varepsilon_{ijkt}. \end{aligned} \tag{1}$$

IC_{ijkt} represents import charges and is specified in logarithm form, where i indexes US ports, j indexes foreign ports, k indexes six-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 (β_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 β_2. $Valwgt_{ijkt}$ is the US 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 β_3 is expected to have a positive sign as well. $Cont_{ijkt}$ is the percent of shipments between ports 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 β_4 should have a negative 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 the weight or value of the product. The following two terms are included to account for trade imbalances between foreign and US 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 β_7 and β_8 to be positive and identical unless traveling unladen into a US port is systematically more or less costly than traveling unladen out of a US port.

The final sets of estimated parameters are the model's fixed effects—sets of dummy variables. η_i is the set of fixed-effects parameters that estimate the separate impact of each US port on import charges holding all other factors constant. These represent the estimated measures of US port efficiencies, with lower coefficients suggesting a more efficient port. In analogous fashion, θ_j are the foreign port fixed-effects parameters and identify foreign port efficiencies. γ_k are product fixed effects that control for other (unobserved) characteristics of products beyond value per weight that affect import charges differently across products. τ_t is a set of year effects that capture macroeconomic and technological shocks to import charges. Finally, ε_{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, α.[7]

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) do not estimate these, but instead include 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. These GCR measures then are external measures, while in the present study the import charge data reveal port efficiencies. There are two main strengths of the fixed-effects 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 from 1995 through 2000 and varies only by country, not over time. Secondly, 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 US port fixed effects in its specification. However, Clark et al. (2004) do not report these, nor do they make the link to using these as measures of US ports' efficiencies.[8] In a later section, we compare our measurements of foreign port efficiencies with the GCR measures, as well as evaluate the effect of our port efficiency measure on international trade flows and find that they are highly correlated.

It is important to stress the differences of our fixed-effects approach to other efficiency measures. Import charges capture 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, is 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. Port tariffs themselves are likely not a good measure of port efficiency since they do not explicitly include costs associated with navigation of the harbor, tide restrictions, more recently, security measures, as well as other factors that can delay shipments into ports, though these costs may be endogenous to the process by which port tariffs are determined.[9]

This raises the question of port competition, the setting of port tariffs, and how these issues may affect interpretation of port fixed effects as port efficiency measures. In order to be competitive, an inefficient port may set lower tariffs than a more efficient port, simultaneously allowing the more efficient port to capture rents. This would tend to equalize import charges across ports, though inefficient ports would be practically constrained from offering negative tariffs. From an economic/cost-efficiency standpoint, one would not be concerned with these endogenous relationships between the different components of the import charges. Thus, for example, this is less of a concern with our analysis at the end of the paper where we examine the relationship between our port efficiency measures and international trade flows. On the other hand, such issues prevent our measure from being an ideal measure of the inherent technical efficiency of a port.

A final related issue is the role of market power in determining import charges, either from ports or carriers. Differences in market power are another factor that may allow some ports to charge higher tariffs than their marginal costs of handling the shipments.[10] This could also distort our port efficiency measures. However, Clark et al. (2004) included measures of market power in their specifications, 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.[11]

4. The 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 US 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 US port data. This dataset is used to construct IC_{ijkt}, $Valwgt_{ijkt}$, $Cont_{ijkt}$, 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 dataset 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 US port codes. The authors developed a correspondence between the two datasets for these US port codes in order to merge the data.

The combined database contains millions of observations, where the unit of observation is a US port, a foreign port, a six-digit HS product code, and year. Such a large dataset presents some computation difficulties. To mitigate this, we first limit our sample to the top 100 foreign and top 50 US ports by import value which cover over 98% and 87%, respectively, of all US import activity over the sample period (excluding oil). Secondly, we focus on non-oil imports only, since oil is relatively unique in having dedicated/specialized ships and port facilities. Despite these limits, we still had to estimate our model for each year, rather than the full sample due to computational constraints. Each year the sample was comprised of hundreds of thousands of observations and required over 10 hours of computation time on a Linux machine with eight gigabytes of RAM using the statistical package STATA.

5. Port Efficiency Estimates

Ordinary least squares (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 0.1297 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 (WGT) and value per unit ($VALWGT$) are also positively correlated with import charges. Import charges increase almost one-to-one with weight, as indicated by

Table 1. OLS Estimates of Determinants of Import Charges for US Imports, 1991–2003

	Dependent variable: import charges												
Regressors	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*
DIST	0.1488*	0.1656*	0.1845*	0.1926*	0.1591*	0.1581*	0.1864*	0.2003*	0.1693*	0.2059*	0.2123*	0.1810*	0.1297*
	(0.0043)	(0.0044)	(0.0043)	(0.0044)	(0.0045)	(0.0044)	(0.0041)	(0.0041)	(0.0045)	(0.0044)	(0.0046)	(0.0042)	(0.0040)
WGT	0.9039*	0.9098*	0.9115*	0.9106*	0.9072*	0.9130*	0.9139*	0.9053*	0.9107*	0.9047*	0.8993*	0.9011*	0.8907*
	(0.0024)	(0.0028)	(0.0026)	(0.0021)	(0.0022)	(0.0016)	(0.0018)	(0.0020)	(0.0023)	(0.0023)	(0.0024)	(0.0023)	(0.0024)
VALWGT	0.5515*	0.5824*	0.5701*	0.5253*	0.5257*	0.5231*	0.5372*	0.5383*	0.5443*	0.5347*	0.5337*	0.5377*	0.5265*
	(0.0044)	(0.0052)	(0.0050)	(0.0039)	(0.0043)	(0.0029)	(0.0033)	(0.0039)	(0.0043)	(0.0044)	(0.0047)	(0.0045)	(0.0045)
CONT	–0.0472*	–0.0491*	–0.0397*	–0.0482*	–0.0570*	–0.0380*	–0.0401*	–0.0545*	–0.0391*	–0.0532*	–0.0649*	–0.0676*	–0.0809*
	(0.0058)	(0.0068)	(0.0064)	(0.0050)	(0.0054)	(0.0039)	(0.0044)	(0.0050)	(0.0056)	(0.0057)	(0.0061)	(0.0058)	(0.0059)
CONT ∗ *WGT*	0.0071*	0.0064*	0.0064*	0.0069*	0.0079*	0.0057*	0.0057*	0.0074*	0.0071*	0.0086*	0.0091*	0.0091*	0.0115*
	(0.0005)	(0.0006)	(0.0006)	(0.0005)	(0.0005)	(0.0004)	(0.0004)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)
CONT ∗ *VALWGT*	–0.0041*	–0.0044*	–0.0067*	–0.0032*	–0.0026*	–0.0022*	–0.0034*	–0.0065*	–0.0102*	–0.0101*	–0.0196*	–0.0097*	–0.0070*
	(0.0010)	(0.0011)	(0.0011)	(0.0009)	(0.0009)	(0.0006)	(0.0007)	(0.0008)	(0.0009)	(0.0010)	(0.0010)	(0.0010)	(0.0010)
IM_IMBAL	–0.0007	0.0020*	0.0052*	0.0079*	0.0026*	0.0024*	0.0022*	0.0039*	0.0031*	0.0040*	0.0018	–0.0000	0.0025*
	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0008)	(0.0007)	(0.0008)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0008)
EX_IMBAL	–0.0016	0.0008	0.0045*	0.0070*	0.0019*	0.0025*	0.0019*	0.0037*	0.0026*	0.0039*	0.0016	–0.0011	0.0014**
	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0008)	(0.0007)	(0.0008)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0008)
No. observations	346,094	353,623	382,870	394,102	402,413	480,968	486,553	556,407	470,490	514,033	482,210	532,606	613,220
R-squared	92	92	92	92	92	91	91	91	91	91	90	91	90
F-statistic	777	787	861	938	940	994	988	1094	923	1006	900	1014	1129

Notes: All variables are logged. A constant intercept term was included, as well as US port fixed effects, foreign port fixed effects, and six-digit HTS product fixed effects. *, **, *** indicate significance at the 1%, 5%, 10% levels, respectively.

a coefficient that averages around 0.90 over the sample years. The coefficient estimates on *VALWGT* suggest that a 10% increase in the value per kilo increases import charges by about 5.5%. As expected, the effect of containerization, everything else equal, is a reduction in import charges, though the elasticity is fairly small, averaging about –0.055 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. The coefficients on these variables are almost always positive and statistically significant as expected, suggesting higher costs for imbalanced trade into the port, though the effects are quite small in magnitude with elasticities less than 0.01.

US Port Efficiencies Measures

The model estimated for our results in Table 1 also includes sets of fixed effects for US ports, foreign ports, and six-digit Harmonized Tariff System (HTS) products. Each of these sets of fixed effects is jointly statistically different from zero at the 1% significance level in all regressions. To facilitate comparisons and discussion, column 1 of Table 2 provides the average fixed-effects estimate for the top 50 (by value) US 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 US 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, the Port of Oakland is excluded from the set of US port fixed effects. Thus, the fixed-effects estimates in Table 2 are relative to the Port of Oakland's effect on import charges. 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-effects coefficient minus one and multiplies by 100.[12] Over two-thirds of our US port fixed effects are statistically different from that of Oakland at the 95% level.

An examination of the US port fixed-effects estimates reveals that many of the Gulf Coast and West Coast ports rank in the upper half of the list, with Richmond-Petersburg topping the list with a coefficient of –0.086, indicating import charges average roughly 8% less than the Port of Oakland. The island ports of Honolulu, Hawaii, and Mayaguez, Puerto Rico, are essentially outliers at the bottom of the list in terms of efficiency with coefficients of 0.589 and 0.438, respectively. Overall, there is a significant range of estimated port efficiencies. Only 13 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

Table 2. US Port Efficiencies

Port name	*Port fixed effects: efficiencies relative to Oakland*	*Port's market share of US import volume over sample years (percent)*	*Change in port efficiency relative to Oakland from 1991–93 period to 2001–03 period*
Richmond-Petersburg, VA	–0.086	0.14	0.155
Port Huron, MI	–0.081	0.40	0.160
Port Hueneme, CA	–0.081	0.91	0.204
Gulfport, MS	–0.074	0.26	–0.066
Cleveland, OH	–0.068	0.09	–0.105
San Francisco, CA	–0.067	0.26	0.124
Baton Rouge, LA	–0.058	0.32	–0.035
New Haven, CT	–0.019	0.12	0.220
Carquinez Strait, CA	–0.005	0.16	–0.100
Oakland, CA	0.000	4.48	0.000
Portland, OR	0.010	1.64	0.012
Galveston, TX	0.020	0.23	–0.016
Chester, PA	0.021	0.29	0.074
West Palm Beach, FL	0.022	0.18	0.051
Newport News, VA	0.036	0.30	0.137
Long Beach, CA	0.043	17.31	0.077
Boston, MA	0.043	0.77	0.078
Mobile, AL	0.047	0.27	0.090
Norfolk, VA	0.049	3.27	0.123
Los Angeles, CA	0.050	18.64	0.036
Houston, TX	0.053	2.79	0.013
Brunswick, GA	0.053	0.62	–0.271
Savannah, GA	0.060	2.33	0.067
Providence, RI	0.062	0.14	–0.264
Wilmington, NC	0.065	0.34	0.167
Jacksonville, FL	0.065	1.86	–0.059
Charleston, SC	0.067	4.26	0.061
Philadelphia, PA	0.071	0.98	–0.015
Beaumont, TX	0.071	0.07	0.489
Baltimore, MD	0.072	3.67	–0.021
New Orleans, LA	0.073	1.75	0.051
Vancouver, WA	0.088	0.17	0.120
New York, NY	0.089	12.75	0.023
Port Everglades, FL	0.104	1.06	–0.069
Detroit, MI	0.110	0.37	–0.056
Miami, FL	0.110	1.86	–0.007
Chicago, IL	0.127	0.15	0.070
Seattle, WA	0.141	6.25	0.017
Tacoma, WA	0.147	4.26	0.018
Richmond, CA	0.152	0.19	0.623
Tampa, FL	0.159	0.21	0.082
Camden, NJ	0.161	0.12	0.136
Wilmington, DE	0.182	0.48	0.021
San Diego, CA	0.185	0.61	–0.021
Gloucester City, NJ	0.230	0.11	–0.093
San Juan, PR	0.341	0.70	0.028
Ponce, PR	0.361	0.12	–0.137
Mayaguez, PR	0.438	0.11	–0.218
Honolulu, HI	0.589	0.14	0.136
Port of South, LA	NA	0.14	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.

import charges. The average port has a fixed effect around 0.08 with a standard deviation for the sample around 0.13.

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 US port's fixed-effects 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 effects for the initial three years of 1991 through 1993 from the port's average fixed effects 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 0.04 relative to the Port of Oakland; in other words, everything else equal, an import shipment to the average port cost roughly 4% more in import charges relative to Oakland in the early 2000s than 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.

Foreign Port Efficiency Measures

Analogous to the estimated US 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 Rotterdam, the Netherlands (the excluded port). Column 1 of Table 3 provides our estimates of the top 30 foreign port fixed effects from the OLS results using our entire sample and ranks them from most efficient to least efficient port. (A table of results for all 100 foreign ports is available at www.uoregon.edu/~bruceb/BW-RIE-FullTable3.pdf.) Column 2 of Table 3 lists the foreign port's market share of total US imports, while column 3 of Table 3 provides the change in the foreign port's fixed-effects 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 all 100 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 US 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 US 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 0.14, but the average change in port efficiency relative to Rotterdam is about −0.05, or a 5% efficiency gain.

The Link between Our Port Efficiency Measures and International Trade

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

Table 3. Foreign Port Efficiencies

Port name	*Port fixed effects: efficiencies relative to Rotterdam*	*Port's market share of US import volume, 1991–2003 (percent)*	*Change in port efficiency relative to Rotterdam from 1991–93 period to 2001–03 period*
Zeebrugge, Belgium	–0.059	0.22	–0.488
Shimizu, Japan	–0.051	0.75	–0.101
Chiba, Japan	–0.027	0.69	0.141
Osaka, Japan	–0.016	1.15	0.102
Bremerhaven, Germany	–0.015	4.74	–0.021
Antwerp, Belgium	–0.011	2.62	0.063
Hakata, Japan	–0.002	0.31	0.167
Rotterdam, Netherlands	0.000	2.57	0.000
Chi Lung, Taiwan	0.015	2.27	0.000
Le Havre, France	0.017	1.35	–0.002
Emden, Germany	0.018	0.79	–0.176
Hamburg, Germany	0.018	0.62	–0.027
Bremen, Germany	0.029	0.76	0.014
Fos, France	0.029	0.21	–0.083
Kawasaki, Japan	0.037	0.25	0.359
Nagoya, Japan	0.055	3.86	–0.059
Toyohashi, Japan	0.055	2.97	–0.260
Tai Chung, Taiwan	0.056	0.30	0.060
Thamesport, United Kingdom	0.062	0.19	NA
Liverpool, United Kingdom	0.063	0.46	–0.064
Kao Hsiung, Taiwan	0.064	2.99	–0.017
Southampton, United Kingdom	0.064	0.81	0.003
Kobe, Japan	0.075	2.60	–0.025
Haifa, Israel	0.075	0.36	–0.176
Tokyo, Japan	0.081	4.95	–0.066
Felixstowe, United Kingdom	0.084	1.18	–0.069
Inchon, South Korea	0.088	0.26	0.138
Puerto Plata, Dominican Republic	0.090	0.20	–0.169
All Other Ports, South Korea	0.097	0.29	0.093
Göteborg, Sweden	0.098	0.83	–0.057

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.

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) report and use the GCR measures for the year 1999 to find a significant effect between port efficiency and trade. An average country-level port efficiency measure for the 1997–99 period using this study's estimated foreign port fixed-effects estimates is constructed, which yields 30 matches with the GCR data. The pairwise correlation is 0.33 between the two measures and is statistically significant at the 10% significance level.[13]

However, to go a significant step further, we examine the explanatory power of the measures of port efficiency for world trade in a standard gravity framework. We focus on trade across countries using our measures of foreign port efficiency and the dataset

Table 4. Significance of Port Efficiency Masures in Gravity Trade Regressions

	Rose's benchmark	*Inclusion of port efficiency measure*	*Inclusion of country-pair fixed effects*
Log Port Efficiency Measure		1.27***	0.32***
		(0.16)	(0.09)
Both Countries in GATT/WTO	0.25	0.14	0.77***
	(0.36)	(0.35)	(0.20)
One Country in GATT/WTO	0.48	0.42	0.88***
	(0.36)	(0.35)	(0.19)
GSP	0.04	0.05	–0.23***
	(0.03)	(0.03)	(0.09)
Log Distance	–0.99***	–0.99***	
	(0.03)	(0.03)	
Log Product of Real GDPs	0.83***	0.82***	1.12***
	(0.01)	(0.01)	(0.21)
Log Product of Real GDPs p/c	0.55***	0.53***	–1.20***
	(0.02)	(0.02)	(0.21)
Regional FTA	0.31***	0.33***	0.06
	(0.09)	(0.09)	(0.04)
Common Language	0.61***	0.63***	
	(0.04)	(0.04)	
Land Border	0.26**	0.27**	
	(0.11)	(0.11)	
Number Islands	0.24***	0.27***	
	(0.03)	(0.03)	
Log Product Land Area	–0.08***	–0.07***	
	(0.01)	(0.01)	
Common Colonizer	0.57***	0.59***	
	(0.10)	(0.10)	
Currently Colonized	0.66***	0.64***	0.03
	(0.08)	(0.08)	(0.03)
Ever Colony	0.46***	0.43***	
	(0.07)	(0.07)	
Year fixed effects	Yes	Yes	Yes
Country-pair fixed effects	No	No	Yes
No. observations	5539	5539	5539
R-squared	0.81	0.81	0.97

Notes: Robust standard errors in parentheses. ** Denotes significance at 5% level; *** denotes significance at 1% level.

on world trade flows constructed by Andrew Rose and available from his website.[14] The data construction and sources are described more fully in Rose (2004). The trade data end with the year 1999, while the port efficiency measures begin in 1991. Thus, our sample spans the years from 1991 through 1999. The number of countries in the sample is limited by where we have estimated foreign port efficiencies (i.e. those in Table 2), which leads to measures for 40 countries.[15]

Column 1 of Table 4 provides estimates of Rose's (2004) benchmark gravity model specification relating the log of total trade (in real dollars) between two countries to a variety of explanatory factors for our sample of years (1991–99) and country pairs where our foreign port efficiency measures are available.[16] The results are qualitatively similar to Rose's results despite a smaller sample.

We next include a measure of port efficiency constructed from our estimated foreign port fixed effects. Since the dependent variable is the combined trade between a country pair, we first add up the weighted-average port fixed effects from both countries. Since our fixed-effects estimates are inversely related to port efficiency, we then construct our port efficiency measure as two minus the sum of the two countries' weighted-average foreign-port fixed effects. We take the log of this port efficiency measure so that we can interpret its coefficient as an elasticity. Column 2 of Table 4 provides estimates when we add our measure of port efficiency to the benchmark specification. The estimated elasticity of trade with respect to port efficiency is quite large—1.27—and statistically significant at the 1% level.

An issue with these estimates of port efficiency, however, is that such a measure may simply proxy for a number of characteristics of the foreign countries that facilitate or hinder trade. If ports have poor infrastructure, contributing to port inefficiency, the country likely has other related infrastructure and development issues that hinder trade. Not controlling for these other country-level characteristics that are likely positively correlated with port efficiency may bias the estimated effect of port efficiency on trade upwards. However, this is where our time-varying measures of port efficiency can overcome this issue, whereas other measures, such as those employed in the cross-sectional analysis of Clark et al. (2004), cannot.

Column 3 of Table 4 provides estimates when we include country-pair fixed effects that control for all time-invariant factors (both observed and unobserved) connected with the country pair. This is a demanding specification to test for port efficiency effects as we now identify such effects only from time variation of our port efficiency measure within each country pair. Our estimates continue to yield a statistically significant correlation between port efficiency and trade, though the elasticity is significantly smaller at 0.32. This implies that a 10% increase in port efficiency leads to a 3.2% increase in real trade between a country pair, which represents a reasonably large, and perhaps more realistic, effect of port efficiency on trade. Clark et al.'s (2004) cross-sectional study finds that an increase in port efficiency from the 25th percentile to the 75th percentile leads to a 25% increase in trade. Our estimates, which control for unobserved country-pair characteristics that may be significantly correlated with port efficiencies, find that a change in port efficiency from the 25th percentile to the 75th percentile leads to a more modest 5% increase in trade.

As a final point of comparison, when we use the log of the GCR measures as our port efficiency variable in the column 2 specification in Table 4, we obtain an elasticity of 3.08 which is statistically significant at the 1% significance level. These GCR port efficiency measures only vary by country, not over time. Thus, we cannot control for unobserved country-level characteristics with the GCR measures, as we can with our port efficiency measures in the column 3 estimates of Table 4. This suggests that use of the GCR measures may lead to a significant overstatement of the estimated effect of port efficiencies on trade volumes due to the inability to include country-level fixed effects.

Product-level Heterogeneity in Estimated Port Efficiencies

A final issue concerns the generality (or stability) of our port efficiency measures across products. Our methodology above provides an estimate of a port's *average* contribution (in percentage terms) to import charges across all products the port may export to the US (in the case of foreign ports) or may import from abroad (in the case of US ports). A natural question is whether ports' efficiencies vary significantly across products. Our preliminary investigations suggest that rankings of port efficiency using our methodology can vary across products. As an example, our earlier version of this paper (Blonigen and Wilson, 2006) provides separate rankings of US ports for autos and steel products, which are different from each other, as well as the general rankings of US ports' efficiencies.

These differences in product-level efficiencies within ports are potentially problematic for our estimates of average port efficiency and their estimated correlations with international trade flows. The concern is that changes in product composition at the port level over time could be driving the positive correlation with trade flows, not changes in the ports' inherent efficiencies. A way of handling this statistically is to include port-by-product specific effects into our estimation procedure. While theortically plausible, as a practical matter, this approach substantially increases the number of fixed effects to be estimated in a model that already pushes computation limits.

However, if product composition at the ports is stable over our panel of years (1991–99) in the gravity model estimates, then we can be reasonably confident that product composition changes are not affecting the relationship between port efficiencies and international trade flows. To evaluate this possibility, we calculate the correlation between foreign ports' two-digit product-level US export values in 1999 and 1991 as well as the same correlation at the four-digit level. The result yields strong and statistically significant correlations of 0.86 for two-digit levels and 0.82 for four-digit levels. These results do not suggest that the composition of products has changed dramatically over time. Thus, we believe this issue is unlikely to be significantly biasing our estimates of the relationship between port efficiency and trade flows.[17] Nevertheless, exploring the factors behind the heterogeneity in port efficiency across products is clearly an area for future research.

6. Conclusions and Future Research

This study provides new measures of ocean port efficiencies through simple statistical tools using US 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 US 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 policymakers, the readily available measures of port efficiency can be used by future researchers to examine myriad new issues, including the evolution of port efficiencies over time and its effects on international trade flows and country-level growth. Importantly, we show that our port efficiency measures allow one to more credibly estimate the effect of port efficiencies on international trade flows. Our measures vary over time, allowing us to control for unobserved country-level heterogeneity in our gravity trade specifications, without which we show one can severely overestimate the impact of port efficiencies on international trade flows.

References

Bichou, Khalid and Richard Gray, "A Logistics and Supply Chain Management Approach to Port Performance Measurement," *Maritime Policy Management* 31 (2004):47–67.

Blonigen, Bruce A. and Wesley W. Wilson, "New Measures of Port Efficiency using International Trade Data," NBER working paper 12052 (2006).

Clark, Ximena, David Dollar, and Alejandro Micco, "Port Efficiency, Maritime Transport Costs and Bilateral Trade," NBER working paper 10353 (2004).

Estache, Antonio, Marianela Gonzalez, and Lourdes Trujillo, "Efficiency Gains from Port Reform and the Potential for Yardstick Competition: Lessons from Mexico," *World Development* 30 (2002):545–60.

Estache, Antonio, Beatriz Tovar de la Fe, and Lourdes Trujillo, "Sources of Efficiency Gains in Port Reform: a DEA Decomposition of a Malmquist TFP Index for Mexico," *Utilities Policy* 12 (2004):221–30.

Global Competitiveness Report, Cambridge, MA: Harvard University; Geneva, Switzerland: World Economic Forum, 1996–2000 (various years).

Hummels, David, "Toward a Geography of Trade Costs," mimeo, Krannert School of Management, Purdue University (2001).

MacHalaba, D., "In California, Santa's Goods Face Port Delays," *Wall Street Journal*, 14 October (2004):B1.

Martinez-Budria, E., R. Diaz-Armas, M. Navarro-Ibanez, and T. Ravelo-Mesa, "A Study of the Efficiency of Spanish Port Authorities using Data Envelopment Analysis," *International Journal of Transport Economics* 26 (1999):237–53.

Roll, Y. and Y. Hayuth, "Port Performance Comparison Applying Data Envelopment Analysis (DEA)," *Maritime Policy and Management* 20 (1993):153–61.

Rose, Andrew K., "Do We Really Know that the WTO Increases Trade?" *American Economic Review* 94 (2004):98–114.

Sanchez, Ricardo J., Jan Hoffmann, Alejandro Micco, Georgina V. Pizzolitto, Martin Sgut, and Gordon Wilmsmeier, "Port Efficiency and International Trade: Port Efficiency as a Determinant of Maritime Transport Costs," *Maritime Economics and Logistics* 5 (2003):199–218.

Tongzon, Jose, "Efficiency Measurement of Selected Australian and Other International Ports using Data Envelopment Analysis," *Transportation Research A: Policy and Practice* 35 (2001):113–28.

US Department of Transportation, Maritime Administration, *Report to Congress on the Performance of Ports and the Intermodal System*, Washington, DC: US Department of Transportation, Maritime Administration (June 2005).

Wang, Teng-Fei, Kevin Cullinane, and Dong-Wook Song, "Container Port Production Efficiency: a Comparative Study of DEA and FDH Approaches," *Journal of Eastern Asian Society for Transportation Studies* 5 (2003):698–713.

Wilson, John S., Catherine L. Mann, and Tsunehiro Otsuki, "Trade Facilitation and Economic Development: a New Approach to Quantifying the Impact," *World Bank Economic Review* 17 (2003):367–89.

Notes

1. See Hummels (2001) for analysis of other transportation frictions affecting international trade flows.

2. 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).

3. Similarly, Sanchez et al. (2003) use cross-sectional survey data on port efficiency to examine transport 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.

4. The US Army Corps of Engineers (ACE) also conducts approximately 10-year surveys of all facility locations in US 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

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.

5. 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.

6. Clark et al. (2004) also include a measure of import volume between the foreign port and all US coastal ports. Such a measure could capture congestion effects or economies of scale effects on import charges. We see these effects as related directly to port efficiency and thus do not include such a regressor so that our port fixed-effects estimates capture these congestion and scale effects. Further, estimation in such a case may be complicated by the possible joint determination of volume and efficiency. Later, we assess the effects of efficiency on trade. Finally, we also estimated the model with and without trade volumes and find that the coefficients in Table 1 are qualitatively the same with very similar numerical values.

7. Clark et al. (2004) also include a measure of port volume as an explanatory variable to control for possible congestion effects on import charges. We exclude this regressor since we want to capture such effects in our port fixed-effects estimates. Our estimates are virtually identical whether we include such an explanatory variable or not.

8. On a more technical note, Clark et al. (2004) specify 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.

9. 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.

10. Note that the issue of market power is different from the issue raised above, which could occur in a perfectly competitive market with differences in technical efficiency of the ports (at least in the short run). In other words, the issue above is about the more efficient ports simply gaining infra-marginal rents due to their efficiency advantages.

11. 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.

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

13. We note that the relatively small number of observations is due to the fact that there are only 41 different countries represented in our 100 foreign port estimates, and a number of these are not in the GCR database.

14. The URL for the website is: http://faculty.haas.berkeley.edu/arose/RecRes.htm#Software.

15. Taiwan is not included because Rose's dataset does not include this country.

16. Three variables in Rose's (2004) benchmark specification are excluded here because they do not vary across observations in our more limited sample: currency union, number landlocked, and common country.

17. We also note that we get very similar port rankings when we estimate port efficiencies using data on containerized-only imports and qualitatively similar estimated effects of these port efficiency measures on trade.