ASSESSING THE ROLE OF PORT EFFICIENCY AS A DETERMINANT OF MARITIME TRANSPORT COSTS

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Introduction

Approximately 80 percent of global trade by volume and over 70 percent of global trade by value are carried by sea worldwide, making maritime transport an economically vital activity (UNCTAD, 2018). In Canada, ports are the main point of entry for imported containerized manufactured goods, which are then distributed throughout Canada or transhipped to the United States (US). Situated in Western Canada, the Port of Vancouver is Canada's largest port in terms of traffic volume, having handled 142.1 million tonnes (Mt) of traffic in 2017, predominantly to and from Asian markets. The Port of Montreal is Canada's second largest container port, having handled 38 Mt in 2017, predominantly from trade with Europe. The Port of Halifax is the largest container port in Atlantic Canada, having handled 4.6 Mt in 2017, which amounts to most of the region's trade (Transport Canada, 2018).

Ports are complex places where multiple activities take place to facilitate the movements of goods to and from distant locations. For example, consider the process of handling an inbound container. The arriving ship must be cognisant of channel depths as it attempts to navigate to an available berth (assuming one is available and water depths permit). Containers are then offloaded, which is dependent on a number of factors including the available labour, capital (e.g., cranes), and storage space in the container yard. Landside transportation modes (truck and rail) are then subject to interactions with other transportation activities, often resulting in congestion due to limited road and rail capacity. Also notable are the necessary inspections that happen at the gate (e.g., Canada Border Service Agency). Even by this brief and simplified description, it should be clear that the study of ports as homogeneous entities is difficult.

Due to this inherent complexity, the literature on maritime logistics has struggled to identify a consistent measure of port efficiency (Dappe, Jooste, and Suárez-Alemán, 2017). Rather, port efficiency can be measured many different ways, such as by average truck turnaround time, berth utilization, vessel turnaround time, and so on. Arisha and Mahfouz (2009) review the literature and group the measurements into five categories: ships and vessels, resources (cranes, labourers), materials (containers or cargos), infrastructure, and port authorities. In Canada, Transport Canada launched the Port Utilization Indicators (PUIs) project in 2009, with the overarching objective of developing a set of port utilization indicators at a national level to assist ports in monitoring operational performance over time. The development of the PUIs was a response to a policy challenge to provide evidence-based information about the efficiency of Canadian supply chains in order to support national gateways policy and address common misperceptions on reliability of the Canadian system.

Given growing international trade and recognition of marine ports as necessary components in facilitating trade, it is important to understand the linkages between port performance (efficiency) and trade costs. Previous studies have relied predominantly on proxy measures (e.g., the results of Data Envelope Analysis (DEA) or questionnaires) to measure port efficiency, finding a statistically significant relationship between higher port efficiencies and lower maritime transport costs. On the other hand, a number of factors influence maritime transport costs. For example, container freight rates are influenced by: shipping distance; service

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charges; season; currency exchange rates; fines and fees; terminal fees; bunker capacity; and container capacity (Marine Insight, 2016).

The primary objective of this paper is to assess the role of port efficiency as a determinant of maritime transport costs in Canada. Linear and log-log regression models of container freight rates as a function of PUIs are developed to determine which, if any, of the ports' activities are related to container freight rates. Unlike previous studies that relied on proxy measures, this study tests several empirical measures of port efficiency, which have been collected by Canadian port authorities over several years.

The remainder of the paper is organized as follows. The following section provides a review of previous models of port efficiency and maritime transport costs. The next section introduces the data and methods used in this study. The detailed modelling results are then presented and discussed. The paper closes with a summary of key findings.

Literature Review

Prior studies have linked port efficiency measures to trade costs in different ways. Some studies examine port-to-port maritime transport costs (e.g., Micco and Perez, 2002; Sanchez, Hoffmann, Micco, Pizzolitto, Sgut, and Wilmsmeier, 2003; Clark, Dollar, and Micco, 2004) while others focus on country-to-country maritime transports costs (e.g., Wilmsmeier, Hoffmann, and Sanchez, 2006; Abe and Wilson, 2009; Abe and Wilson 2011; Dappe et al., 2017). Accordingly, prior studies have used individual measures of port efficiency (Sanchez et al., 2003) as well as aggregated per-country measures of port efficiency (Micco & Perez, 2002; Clark et al., 2004; Wilmsmeier et al., 2006; Abe & Wilson, 2009; Abe & Wilson 2011; Dappe et al., 2017).

Moreover, maritime transport costs have also been measured differently. Some studies include the aggregate cost of freight, insurance, and other charges (e.g., import charges that may cover the costs of services associated with transport such as fees paid to port and storage brokers and freight forwarders), excluding duties (Micco & Perez, 2002; Clark et al., 2004; Sanchez et al., 2003; Abe & Wilson, 2011; Dappe et al., 2017). Other studies have subtracted FOB values from CIF values, which includes freight and insurance, but excludes other charges (Abe & Wilson, 2009). One study was able to separate the freight charges (i.e., not including the insurance charges) (Wilmsmeier et al., 2006). Despite measurement differences for both port efficiency and maritime transport costs, the general consensus of these studies is the same: higher port efficiencies are associated with lower maritime transport costs.

Using an aggregated per-country measure of port efficiency from the World Economic Forum's (WEF's) Global Competitiveness Report (GCR), Micco and Perez (2002) and Clark et al. (2004) determine that improving port efficiency from the 25^{th} to the 75^{th} percentile reduces shipping costs to the US by 12 percent. That is, when port efficiency is measured with the GCR index, an improvement in port efficiency from the 25^{th} to 75^{th} percentile (i.e., from a score of 3.4 to 5.6 out of 7, respectively) generates a maritime transport costs decline of around 12 percent. Similarly, Wilmsmeier et al. (2006) use six measures from the GCR, finding that of all of the port characteristics investigated, the estimated elasticity for port efficiency is the highest; doubling port efficiency in a pair of ports has the same impact on international transport costs as halving the distance between them.

Sanchez et al. (2003) focus on the determinants of shipping costs to the US with a focus on Latin American countries using direct information (i.e., port indicators) gathered by way of questionnaires. Since different port efficiency measures were statistically significant, and are estimated with the expected signs in the regressions, they conclude that more efficient ports are clearly associated with lower freight costs after controlling for distance, type of product, liner services availability, and insurance costs, among others. Abe and Wilson (2009) and Abe and Wilson (2011) estimate an index of physical capacity and congestion at East Asian ports, and include it as an explanatory variable in their transport cost regression models to measure its effects on Japanese and US import charges, respectively. They find a 10 percent reduction in their port congestion index results in a 1 percent reduction in ocean transport costs. Dappe et al. (2017) study 12 developing countries in the Indian and Western Pacific Oceans and 35 container ports using output-oriented intertemporal DEA measures for port efficiency. They find that a 0.1 increase in efficiency levels for the port sector in a country reduces the maritime transport costs of its exports to the United States by 2.3 percent; raising port efficiency from the 25th to the 75th percentile reduces transport costs by about 3.6 percent.

Data

In this study, maritime transport costs are measured using the Drewry Container Freight Rate Insights from March 2011 to February 2017. The Insights provide container freight rates (for odd months only) between three Canadian ports [Canada East Coast (Montreal), Canada West Coast (Vancouver), and Canada East Coast (Halifax)] and 16 trade partners [Korea (Busan), South China (Yantian), Central China (Shanghai), North China (Tianjin), Hong Kong, Singapore, India (Nhava Sheva), U.A.E (Jebel Ali), Saudi Arabia (Jeddah), UK (Felixstowe), North Continent Europe (Rotterdam), West Med (Genoa), Brazil (Santos), South Africa (Durban), West Africa (Lagos), and Australia (Melbourne)]. These data are like-for-like spot freight rate benchmarks drawn from a stable panel of buyers (approximately 30 freight forwarders and Non-Vessel-Operating Common Carriers (NVOCCs)) who provide Drewry with their “buy rates” and market data, which Drewry uses to calculate monthly and weekly average spot rates, ensuring continuity and comparability of data. The rate benchmarks are for Full Container Loads and include the base ocean rate, the Terminal Handling Charge both at the origin and destination, the fuel surcharge and all other surcharges; they do not include inland transport costs.

Canada is fortunate to have primary sources of data on port performance, owing to the multi-phase PUI project that commenced in late 2008. The primary goal of that project was to develop a set of utilization indicators at a national level to assist ports in monitoring their operational performance over time. Table 1 summarizes the monthly indicators being collected as part of that project, including at the ports of Vancouver, Montreal, and Halifax. The development of these indicators is described in-depth by Brooks, Frost, Kymlicka, and Pallis (2008), and was recently assessed by Brooks (2015) for the Canadian Transportation Act Review in 2015.

Table 1 Intermodal Port Utilization Indicators

Indicator	Units	Purpose
Average Truck Turnaround Time	Minutes	Landside performance
Berth Utilization	TEU per meter of berth	Asset utilization
Vessel Turnaround Time	Seconds/TEU Hours/vessel call	Waterside performance
Average Container Dwell Time	Days	Supply chain performance
Dwell Target - % under 72 hours	Percentage	Rail Reliability
Gross Port Productivity	TEU per gross hectare	Land utilization
Vessel On-Time Performance	Percentage	Vessel reliability
Crane Productivity of Port	Lifts/hour	Stevedoring performance
Number of Vessel Calls	Vessel calls	Records total vessel calls
Container Throughput	TEUs	Captures total throughput
Average Vessel Load	TEU/vessel call	Vessel turnaround performance

Data were gathered for other explanatory variables that were hypothesized to impact container freight rates. In general, distance is one of the main determinants of trade costs (e.g., gravity models). Data on sea route distances between ports were obtained from Marine Traffic’s Port to Port Voyage Planner (MarineTraffic, 2019). These data are based on actual movements of vessels. Monthly crude oil prices were obtained from the World Bank Commodities Price Data (The “Pink Sheet”) (World Bank, 2019). Since container freight rate is the dependent variable in the model specifications, shipment-specific independent variables were not required for this study’s analysis (e.g., value to weight ratios).

Method

Using the data described in the previous section, container freight rates models were developed for imports and exports, for both 20ft and 40ft containers. The export models (20ft/40ft) take the form:

$$pe_{ijt} = \beta_0 + \beta_1 d_{ij} + \beta_2 o_t + \beta_3 PUI_{it} + \gamma_i + \delta_j + \eta_t + \varepsilon_{ijt} \quad (1)$$

where pe_{ijt} is the price of shipping a container from a Canadian port *i* to a foreign port *j* at time period *t* ($), β_0 is a constant, d_{ij} is the port-to-port maritime transportation distance between ports *i* and *j* (nautical miles), o_t is the world oil price at time period *t* ($), PUI_{it} is a PUI for Canadian export port *i* at time *t* (units in Table 1), γ_i is the fixed-effect for Canadian export port *i*, δ_j is the fixed-effect for foreign import port *j*, η_t is the fixed-effect for time period *t*; and ε_{ijt} is the residual error (assumed normally distributed). Similarly, the import models (20ft/40ft) take the form:

$$pi_{ijt} = \beta_0 + \beta_1 d_{ij} + \beta_2 o_t + \beta_3 PUI_{jt} + \gamma_i + \delta_j + \eta_t + \varepsilon_{ijt} \quad (2)$$

where pi_{ijt} is the price of shipping a container from a foreign port *i* to a Canadian port *j* at time period *t* ($), β_0 is a constant, d_{ij} is the port-to-port maritime transportation distance between ports *i* and *j* (nautical miles), o_t is the world oil price at time period *t* ($), PUI_{jt} is a PUI for Canadian import port *j* at time *t* (units in Table 1), γ_i is the fixed-effect for foreign export port *i*, δ_j is the fixed-effect for Canadian import port *j*, η_t is the fixed-effect for time period *t*, and ε_{ijt} is the residual error (assumed normally distributed). Different fixed-effects for time, η_t, are considered in this study, fixing either each year (*t* = 2011, 2012,… 2017) or each month of each year (March 2011, May 2011, … January 2017) in the models.

Models were estimated using Ordinary Least Squares (OLS) regression. The “best” model specifications (i.e., variables and functional forms) were determined by testing several PUIs in the model specifications (e.g., average truck turnaround time, berth utilization, vessel turnaround time, etc.) and experimenting with both linear and log-log model specifications, through processes of both backward and stepwise selection. Variables were assessed based on intuition (i.e., correct parameter sign) and statistical significance (i.e., *t*-tests and *p*-values). Variables that were not statistically significant at the 10% level of significance were dropped from model specifications. Model fit was assessed based on the R^2 goodness-of-fit.

Using the estimated model coefficients, elasticities were calculated for statistically significant explanatory variables. An elasticity is a measure of a variable's sensitivity to a change in another variable, quantified as the ratio of the percentage change in one variable to the percentage change in another variable. Since a linear regression coefficient (such as those in Equations 1 and 2) provides an estimate of the impact of a *unit* change in an independent variable on the dependent variable (measured in *units* of the dependent variable), elasticities for linear models are determined by:

$$E_X = \frac{\%\Delta Y}{\%\Delta X} = \frac{dY}{dX}\left(\frac{X}{Y}\right) = \beta_X \left(\frac{X}{Y}\right) \quad (3)$$

where Y is the dependent variable (pe_{ijt} or pi_{ijt} in Equation 1 or 2), X is one of the independent variables (on the right hand side of Equations 1 or 2), and β_X is the regression coefficient corresponding to X. Since elasticities are not constant in a linear model, they were evaluated at the point of the means ($\bar{X}, \bar{Y}$). The resulting elasticities can be interpreted as “a 1% increase in X leads to a E_X% change in Y.” For log-log models, the regression coefficients *are* the elasticities, which are constant across all values.

Results and Discussion

Table 2 shows the results of the final linear regression model specifications. Distance coefficients indicate a one nautical mile increase in distance is associated with a $0.11 to $0.31 increase in freight rates (elasticities from 0.38 to 0.63 at the mean values). These elasticities are slightly higher than those reported in previous literature, which ranged from 0.05 (Sanchez et al., 2003) to 0.37 (Wilmsmeier et al., 2006), although those studies analyzed data from 1999 and 2002, respectively, and reflect vastly different shipping routes (Latin America to US and intra-Latin America, respectively). Oil price coefficients indicate a $1/barrel increase in the average oil price is associated with a $6.20 to $14.47 increase in freight rates (elasticities from 0.16 to 0.38 at the mean values). Average truck turnaround times indicate a one minute increase in average truck turnaround time is associated with a $5.86 to $12.94 increase in freight rates (elasticities from 0.05 to 0.09 at the mean values). While average truck turnaround time does not directly impact container freight rates, it may be positively correlated with freight rates due to its potential indication of congestion (or lower fluidity). Vessel turnaround time coefficients indicate a one hour increase in vessel turnaround time is associated with a $3.89 to $10.47 increase in freight rates (elasticities from 0.06 to 0.10 at the mean values), suggesting longer wait times are associated with increased freight rates. This result is consistent with the findings of Sanchez et al. (2003), who find the port ship stay has a positive effect on waterborne transport costs.

The number of vessel calls coefficients indicate an increase of one vessel call is associated with an $11.84 to $14.03 decrease in freight rates (elasticities from -0.18 to -0.24 at the mean values), suggesting increased competition reduces freight rates. Container throughput coefficients indicate an increase in one TEU is associated with a $0.003 to $0.014 decrease in container freight rates (elasticities from -0.12 to -0.49 at the mean values), suggesting ports with higher throughputs are associated with lower freight rates. This result is consistent with Micco and Perez (2002), who explain this relationship through economies of scale in shipping. Similarly, average TEU/vessel call coefficients indicate an additional TEU/vessel is associated with a $0.10 to $0.28 decrease in freight rates (elasticities from -0.07 to -0.27 at the mean values), once again reflecting economies of scale.

Table 3 shows the results of the final log-log regression model specifications. Distance coefficients (elasticities) range from 0.49 to 0.67, indicating a 10 percent increase in distance is associated with a 4.9 to 6.7 percent increase in freight rates. Berth utilization (TEU/meter) elasticities range from 0.11 to 0.45, suggesting higher berth utilizations are associated with higher freight rates. Berth utilization is a measure of asset utilization, and higher utilizations may be positively correlated with increased congestion and hence greater transport times and costs. For example, Abe and Wilson (2009; 2011) found their port congestion index, measured by the sum of the loaded and unloaded containers (TEUs) divided by the sum of the estimated full physical port capacity (TEUs), takes a significantly positive coefficient in their studies of freight rates to Japan and the United States. Vessel turnaround time has an elasticity of 0.13, suggesting longer wait times are associated with higher container freight rates. Average container dwell time elasticities range from 0.06 to 0.11, which is consistent with the positive coefficient found by Sanchez et al. (2003). Similar to average truck turnaround times, while average container dwell time does not directly impact container freight rates, it may be positively correlated with container freight rates due to its potential indication of congestion (or lower fluidity).

Container throughput elasticities range from -0.51 to -0.53, suggesting ports with higher throughputs are associated with lower freight rates. Similarly, average TEU/vessel call has an elasticity of -0.09. As before, both of these findings are believed to be the result of economies of scale.

Table 2 Linear Regression Results

	Import				Export			
	20 ft		40 ft		20 ft		40 ft	
Fixed Effects	Year	Month	Year	Month	Year	Month	Year	Month
Average Truck Turnaround Time (Minutes)					5.86 **	7.65 ***	11.25 ***	12.94 ***
Berth Utilization (TEU/Meter)	31.83 ***	26.42 ***	38.63 ***	33.72 ***				
Vessel Turnaround Time (Hours)	9.03 ***		10.47 ***		3.89 **			
Number of vessel calls	-13.26 **	-14.03 **					-11.84 ***	
Container Throughput (TEU)	-0.01 ***	-0.005 *	-0.01 ***	-0.01 ***				-0.003 **
Average TEU/vessel call	-0.28 ***	-0.26 ***	-0.12 *	-0.10 *			-0.10 **	
Oil Price		8.30 ***		13.60 ***		7.94 ***	6.20 **	14.47 ***
Distance	0.23 ***	0.23 ***	0.31 ***	0.31 ***	0.11 ***	0.11 ***	0.16 **	0.16 ***
R^2	0.61	0.64	0.67	0.69	0.65	0.67	0.73	0.75
Observations	1663	1663	1663	1663	1668	1668	1668	1668

* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 3 Log-Log Regression Results

	Import				Export			
	20 ft		40 ft		20 ft		40 ft	
Fixed Effects	Year	Month	Year	Month	Year	Month	Year	Month
Average Truck Turnaround Time (Minutes)					0.06 *	0.11 ***	0.15 ***	0.16 ***
Berth Utilization (TEU/Meter)	0.42 ***	0.11 *	0.45 ***	0.12 *				
Vessel Turnaround Time (Hours)					0.13 ***			
Average Container Dwell (Days)	0.10 ***		0.11 ***		0.06 **		0.06 ***	
Container Throughput (TEU)	-0.51 ***		-0.53 ***					
Average TEU/vessel call					-0.09 *			
Oil Price		0.23 ***		0.26 ***		0.52 ***		0.51 ***
Distance	0.67 ***	0.66 ***	0.67 ***	0.67 ***	0.49 ***	0.49 ***	0.52 ***	0.52 ***
R^2	0.73	0.69	0.79	0.74	0.71	0.73	0.78	0.8
Observations	1260	1663	1260	1663	1170	1170	1170	1170

* significant at 10%; ** significant at 5%; *** significant at 1%

Conclusion

Few previous studies have focused on the role of port efficiency as a determinant of maritime transport costs. Due to data limitations, five previous studies focused on imports to the United States, one study examined imports to Japan, and one study focused on intra-Latin America trade. Most studies relied on indirect measures of port efficiency such as the WEF's GCR or aggregated measures from DEA in their quantitative analyses. Only the study of intra-Latin America trade analyzed disaggregate measures of port efficiency. Notwithstanding the small sample of studies and generally indirect measurement techniques employed, prior literature consistently found that higher port efficiencies are associated with lower maritime transport costs.

This is the first study to use a rich set of empirical data spanning several years to examine the role of port efficiency as a determinant of maritime transport costs. Six years of container freight rate data for both 20 ft. and 40ft. containers were analyzed for both imports and exports between three of Canada's largest ports and 16 trade partners. Eleven port efficiency measure were analyzed, allowing for the unique determination of each measurement's elasticity, and an assessment of its statistical significance. Using this rich data set, the analysis determined that longer distances, higher oil prices, higher berth utilizations, longer truck turnaround times, longer container dwell times, and longer vessel turnaround times are associated with higher container freight rates. On the other hand, higher container throughputs, more vessel calls, and more TEUs per vessel are associated with lower container freight rates (through economies of scale).

Evidence from Canada confirms the overall consensus developed in prior literature: higher port efficiencies are associated with lower maritime transport costs. The results in this study also corroborate prior studies at a more detailed level:

- Longer vessel turnaround times are associated with higher maritime transport costs (Sanchez et al., 2003);
- Increased container throughputs are associated with lower maritime transport costs (Micco and Perez, 2002);
- Increased asset utilization (as measured by berth utilization in this study) is associated with higher maritime transport costs (Abe and Wilson, 2009; 2011); and
- Increased container dwell times are associated with higher maritime transport costs (Sanchez et al., 2003).

Results presented in this paper should be interpreted with an understanding of a few key study limitations. First, the container freight rates used in this study are spot rates, not contracted rates. For this reason, real world containers would be shipped at different (presumably lower) rates under contract. Unfortunately, a sample of real world shipment data (under contracted freight rates) is not available in Canada. Second, although the results presented in this paper were tested for statistical significance, correlation does not imply causation. In other words, the positive and negative associations found in this study may be the result of unobserved covariates. There is however, reasonable certainty in the direction of causation, as freight rates are *not* expected to impact most port efficiency measurements. Third, the PUIs exhibit multicollinearity (not previously discussed for the sake of brevity), allowing for alternative model specifications with minor differences in results. The final model specifications presented in this paper prioritized variables by their explanatory power (i.e., correlation coefficient with freight rates) and statistical significance (i.e., p-values).

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