

CONTAINER PORT EFFICIENCY AND OUTPUT MEASURES

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Abstract

The output of container ports has generally been measured by its TEU throughput, the number of TEUs interchanged from one carrier to another. Unlike TEU throughput, an increase in the container port output measure, TEU throughput per unit of TEU time in port, in the short-run time period (for which port infrastructure is fixed) does imply a decrease in the port's technical inefficiency. This output measure is consistent with measurements utilized by container port managers for investigating reductions in technical inefficiency at their ports – ship loading and unloading service rates. The time that TEUs are in port can be obtained from RFID sensors that are attached to containers.

Key Words: Port Output, Container Port, TEU Throughput, TEU Interchange Service

1. Introduction

Seaborne transport is vital for international trade. Seaborne trade accounts for 77 percent of the total volume of world trade; 16 percent moves overland, 6.7 percent through pipelines and only 0.3 percent by air (Lloyd's MIU, 2007). As of 2007, 50 percent of seaborne trade was containerized (Galhena, 2008).

Ocean container transportation has revolutionized the seaborne transport of international trade. The maiden international voyage of a containership (from the U.S. to Rotterdam) occurred in 1966 – the beginning of the containerization of world trade. For the shipping line, containerization meant less time in port for ships. A containership may be in port for only a few hours (as opposed to a break-bulk ship being in port for a week), resulting in lower ship dockage costs and faster ship turnaround times. Further, fewer ships are needed to carry the same amount of cargo between the same set of ports in a given time period. Also, containerization provides for significant port labor cost savings and port productivity increases. As break-bulk cargo, 20 tons of general cargo could be loaded per hour on a break-bulk ship by a gang of 20 longshoremen; whereas for container cargo, 400 to 500 tons of general cargo could be loaded per hour on a containership using one crane and perhaps half as many longshoremen. For the shipper, less handling meant less frequent damage to cargo and less pilferage of cargo, thereby lowering insurance costs.

Ocean container transportation of international trade has resulted in significant reductions in the transportation and other logistics costs (such as inventory costs) of this trade, thereby being a major stimulant to the growth in international trade. In 1980 seaborne containerized world trade was 36.4 million TEUs (twenty-foot-equivalent

units), increasing to 87.1 and 157.6 million TEUs in 1990 and 1996, respectively (Staff, 1997). By 2006 this number had increased to 442 million TEUs and is expected to increase to 673 million TEUs by 2011 (Galhena, 2008).

An important determinant of seaborne transportation costs is port efficiency. Clark, Dollar and Micco (2004) investigated this relationship by using several proxies for port efficiency -- the normalized total square number of the largest seaports in a country and a country's Gross Domestic Product per capita. Country-level measures were used since: "Unfortunately, there is not much comparable information about port efficiency -- at port level -- to be used in a cross-country analysis" (Clark, Dollar and Micco, 2004, p. 431). Clark, Dollar and Micco (2004) conclude that an improvement in port efficiency from the 25th to the 75th percentile reduces seaborne transportation costs by more than 12 percent or the equivalent of 5,000 miles in distance. A 10 percent improvement in port efficiency for two ports (on different coasts) is expected to reduce seaborne transportation costs between the two ports by 3.8 percent (Wilmsmeier, Hoffmann and Sanchez, 2006).

This paper contributes to our knowledge of the measurement of port efficiency. Is there one overall measurement of container port productive efficiency (at the port level) that can be used in comparative analyses of productive efficiencies among container ports worldwide? If such a measurement exists, it can also be used to investigate port efficiency relationships, e.g., the impact of improvements in container port efficiency on the inventory and other logistics costs of containerized seaborne trade. This paper provides theoretical evidence that one such measure is the container port output measure, TEU throughput per unit of TEU time in port, i.e., an increase in this measure denotes a decrease in container port inefficiency. Further, the paper provides evidence that the

container port output measure, TEU throughput, used in container port relative efficiency studies (Cullinane, 2002) does not necessarily denote a decrease in container port inefficiency from increases in the output.

2. TEU Throughput

The output of container ports has generally been measured by its TEU throughput, the number of TEUs that past through the port from one transport carrier to another.

Container ports with greater TEU throughput have been claimed to be more productive than ports with less TEU throughput. TEU throughput has also been used in Data Envelopment Analysis (DEA) and stochastic frontier analysis models for investigating the relative technical efficiency among container ports (Cullinane, 2002; Cullinane and Song, 2006), where technical efficiency is defined as the maximum output obtainable in the use of a given level of resources. An argument for using TEU throughput as the output measure of a container port is that irrespective of a container's size and weight, the port resources used in the movement of a single container is more or less the same.

Whether TEU throughput is justified as a measure of container port output will depend upon how it is used. Cochrane (2007) argues that as an output in frontier analyses of container ports, TEU throughput may result in misleading conclusions. Specifically, the frontier analysis requirement of homogeneity (e.g., ports have the same types of resources) may not be satisfied. Differences in types of resources may be due to the use of differing technologies by container ports. Wide differences in the ratios of different types of containers may also contribute to the lack of homogeneity. For example, wide differences in the ratio of twenty foot containers to forty foot containers handled will

affect the number of container lifts at the quay and the spreader technology adopted by the port. Wide differences in the ratio of import and export containers to transshipment containers will affect the ratio of land to water container movements, since transshipment containers require less terminal yard space.

3. Container Port Production Functions

The theoretical port production functions utilized heretofore in the estimation of port production functions (via econometric and frontier analysis procedures) are those found in the physical production function literature, i.e., for which physical products are produced as opposed to services provided (Chang, 1978; Bendall and Stent, 1987; Liu, 1995; Dowd and Leschine, 1990; and Cullinane and Song, 2006). Specifically, these functions express the amount of a physical output produced by a firm as a function of the resources that the firm utilizes in producing the output. If the output is the maximum output that can be produced by a given level of resources, the firm is then technically efficient, i.e.,

$$\text{Output} = f_1(\text{Resources}) \quad (1)$$

For container ports, the output in this function is normally measured (as stated above) as TEU throughput, i.e.,

$$\text{TEU Throughput} = f_2(\text{Resources}) \quad (2)$$

Rather than utilizing physical output production functions, service output production functions should be considered instead. A container port does not produce TEUs but rather provides TEU interchange service for the TEUs that it receives, i.e., import TEUs

received from ocean vessels are interchanged with domestic vessels and land vehicles and vice versus for export TEUs; transshipment TEUs are interchanged between vessels. In order for a container port to provide TEU interchange service, at least two parties must be in agreement. If either party is not in agreement, no port TEU interchange service will occur. Specifically, carriers (or transportation firms) must be willing to transport containers to and from the port and the port must be willing to interchange the received containers from one vessel or vehicle to another. If the port is unwilling to accept containers, even though carriers are willing to provide it with containers, no port TEU interchange service will occur. If carriers are unwilling to provide the port with containers, even though the port is willing to accept containers, no port TEU interchange service will occur. The port can not force carriers to provide it with containers and carriers can not force the port to accept its containers. The exception is when ports are leased or owned by the carriers.

The production function for a freight carrier relates the maximum amount of freight transportation service provided by the carrier to the level of resources utilized by the carrier in providing the service and the amount of freight that it receives from shippers to be transported (Talley, 1988). By analogy, a container port's production function relates the maximum amount of TEU interchange service provided by the port to the level of resources utilized by the port in providing the service and the number of TEUs that the port receives from carriers, i.e.,

$$\text{TEU Interchange Service} = g(\text{Resources}; \text{TEUs Provided by Carriers}) \quad (3)$$

TEU interchange service is the port service of interchanging TEUs between arriving and departing carrier vessels and vehicles at the port. If the port adheres to this production function in the provision of TEU interchange service, then the port is technically efficient in the provision of TEU interchange service.

Container port physical output production function (2) and container port service output production function (3) are similar and different. They are similar in that both functions have port resources as explanatory variables. They are different in that the dependent (or output) variable of function (2) is TEU Throughput, while that for function (3) is TEU Interchange Service. Function (3) also has an additional explanatory variable, TEUs provided by carriers to the port.

The resources utilized by a container port will vary with the levels of its operating options and the number of TEUs provided by carriers to the port. A port's operating options are the means by which it can differentiate its service (Talley, 2006). Examples of such operating options for a container port are its: ship loading and unloading service rates (TEUs loaded on and off ships per hour) and vehicle loading and unloading service rates (TEUs loaded on and off vehicles per hour). Other port operating options include: channel accessibility and reliability, berth accessibility and reliability, entrance and departure gate reliability, probabilities of ship damage and property loss, probabilities of vehicle damage and property loss and probabilities of port cargo damage and loss (Talley, 2006).

If the amounts of the various resources employed by a container port are the minimum amounts to be employed given the levels of its operating options and number of TEUs

provided by carriers, then this relationship for a given resource is the port's resource function for that resource (Talley, 1988, 2006), i.e.,

$$\text{Resource} = h(\text{Port Operating Options}; \text{TEUs Provided by Carriers}) \quad (4)$$

Proposition 1: If a container port's production function is a physical output production function with output, TEU throughput, then the container port's production function can not be rewritten so that TEU throughput is a production function of the container port's operating options and TEUs provided by carriers.

Proof:

From substituting resource function (4) into TEU throughput production function (2) and rewriting, it initially appears that TEU throughput may be expressed as a function of the container port's levels of operating options and the TEUs provided by carriers.

However, an identity problem arises in that TEU Throughput = TEUs Provided by Carriers, i.e., the TEUs interchanged by the port are the same TEUs provided to the port by carriers. Since output cannot be a function of itself and the function remain a production function, it thus follows that TEU throughput can not be expressed as a production function of container port operating options and TEUs provided by carriers.

Proposition 2: If a container port's production function is a service output production function with output, TEU interchange service, then the container port's production function can be rewritten so that TEU interchange service is a production function of the container port's operating options and TEUs provided by carriers.

Proof:

From substituting resource function (4) into TEU interchange service production function (3) and rewriting, it follows that TEU interchange service is a production function of the container port's operating options and the TEUs provided by carriers, i.e.,

TEU Interchange Service = G(Port Operating Options; TEUs Provided by Carriers) (5)

Here, the problem of the identity between the dependent variable and an explanatory variable does not exist.

In estimating container port production functions, a problem that often arises is the lack of data for the labor resource variable. This problem is often addressed by making the argument that a fixed relationship exists between the amount of equipment deployed and the amount of labor employed by a container port -- thus, providing justification for the omission of the labor resource variable from the estimation. An alternative approach to addressing this problem is to estimate TEU interchange service production function (5) for which resource information is not required.

4. TEU Throughput Versus TEU Interchange Service

TEU Throughput as a container port output measure obviously does not directly reflect the role of the port in creating this throughput, e.g., neither the hours of port interchange service provided nor the distances that TEUs are moved within the port are considered. Since both the port and carrier contribute to the creation of the port's output, why not measure this output in terms of both TEUs and hours of port interchange service, i.e., in terms of TEU interchange service? It is interesting to note that the freight output of U.S.

intercity transportation carriers is often measured in ton-miles – the product of the cargo tonnage provided by shippers to carriers for transport and the vehicle miles of service provided by carriers in transporting this cargo tonnage.

Proposition 3: An increase in a container port's TEU throughput does not imply a decrease in the port's technical inefficiency.

Proof:

Under the assumption that the use of a port's resources can be measured by time in use, Proposition 3 will hold if there is at least one scenario that when TEU throughput increases, the percentage increase in resource time use is greater than the percentage increase in TEU throughput. One such scenario can occur at a port's inland entrance gate -- when more port resource time is required to admit each additional container that enters the port. Hence, Proposition 3 holds.

In order to utilize TEU interchange service in practice as an output of a container port, a specific unit of measurement for this service is needed. If this measurement is to reflect the fact that TEUs are being serviced and the port provides service time to service the TEUs that it receives, a unit of measurement for a container port's TEU interchange service that adheres to these two conditions is the number of TEUs that pass through the port per unit of TEU time in port. For a given time period, the value of this measurement would be determined by dividing the number of TEUs that pass through a port (or are interchanged) by the total time that these TEUs are in port. Note that the numerator of this unit of measurement is TEU throughput. Hence, the number of TEUs that are

interchanged per unit of TEU time in port may also be referred to as TEU throughput per unit of TEU time in port (TEU Ratio).

Proposition 4: An increase in a port's TEU Ratio in the short-run time period (for which port infrastructure is fixed) implies a decrease in the port's technical inefficiency.

Proof:

Under the assumption that the use of a port's resources can be measured by time in use and there are no improvements in port interchange service technology, Proposition 4 will hold if for all possible scenarios for which the TEU Ratio increases, the percentage change in resource time use is less than the percentage change in the number of TEUs handled by the port. All such possible scenarios for which the TEU Ratio increases are listed below:

Scenario 1: TEU throughput increases but there is no increase in the total time that TEUs are in port;

Scenario 2: TEU throughput increases and there is a decrease in the total time that TEUs are in port;

Scenario 3: TEU throughput increases by a greater percentage than the increase in the total time that TEUs are in port;

Scenario 4: TEU throughput does not change but there is a decrease in the total time that TEUs are in port; and

Scenario 5: Both TEU throughput and the total time that TEUs are in port decrease, but the percentage decline for the latter is greater than that for the former.

Note that for each scenario the percentage change in resource time use is less than the percentage change in the number of TEUs handled by the port. Hence, Proposition 4 holds.

The output measure, TEU Ratio, is consistent with measurements utilized by container port managers for investigating reductions in technical inefficiency at their ports. For example, managers of container port authorities often quote values of the port operating options, ship loading and unloading service rates (TEUs loaded on and off ships per unit of time). As these service rates increase, the port's TEU Ratio will also increase, all else held constant. Container port managers also seek to reduce the dwell time of port containers, i.e., storage time per TEU stored. If the dwell time of containers in a port decreases, it also follows that the TEU Ratio will increase, all else held constant.

In a study by Song, Cullinane and Roe (2001), a container port's output was initially described as an interchange service. Specifically, the output was defined as the container turnover derived from the delivery of container terminal services and measured by the revenue received for these services. However, problems arose in the use of revenue as a measure of container port output. Port revenue not related to interchange service, e.g., from property sales, had to be excluded. The wide diversity of accounting systems used by the port terminals in the study resulted in an intractable problem of separating out revenue attributable to different sources. In the end result, the study chose the physical measure of annual container throughput TEUs² instead.

As for TEU throughput, an increase in a port's revenue from interchange service over time does not necessarily imply that the port's productive performance has improved (or

technical inefficiency has declined) over time. In fact, a port's revenue may be increasing over time, while its throughput is decreasing over time. That is to say, since revenue is the product of price and output, increases in a port's prices over time will result in a decline in throughput and rising revenue over time if the demand for port services is price inelastic.

5. Container Time in Port

In order to determine a port's TEU throughput per unit of TEU time in port (TEU Ratio), information on the port's TEU throughput and the time that TEUs are in port need to be known. The latter can be obtained from RFID (Radio Frequency Identification) sensors that are attached to containers. An import container's time in port begins when the oceangoing ship on which it is onboard is berthed at the port and ends when it leaves the port onboard a domestic vessel or land vehicle. An export container's time in port begins when it arrives at the port onboard a domestic vessel or land vehicle and ends when the oceangoing ship on which it is onboard is un-berthed at the port. A transshipment container's time in port begins when the ocean-going ship on which it is onboard is berthed and ends when another oceangoing ship on which it is onboard is un-berthed at the port.

A container's time in port consists of its movement time, storage waiting time and other-than-storage waiting time in port. Movement time is the time that a container is being transported from one area to another area within the port; storage waiting time is the time that a container is in a designated storage area of the port; and other-than-storage waiting time is the time (not in storage) that a container is waiting to be moved to another

area in the port. The latter time, for example, may be the time that a container is: onboard a ship and waiting to be unloaded; at the wharf waiting to be loaded on a ship; and onboard a truck or rail car waiting to depart (or enter) the port. The sum of port movement, storage waiting and other-than-storage waiting times for a given container will be the total time that the container is in port.

Container throughput per unit of container time in port can also be computed for each type of port container (20 footer, 40 footer, 45 footer, 53 footer, import, export and transshipment) as opposed to only computing a port's TEU throughput per unit of TEU time in port (for which containers other than 20 footers would have to be converted into TEUs). These container ratios (for different types of containers) could be used by port managers to investigate technical inefficiencies among types of container throughputs, e.g., by comparing a port's 40 foot container throughput per unit of time in port to a port's 20 foot container throughput per unit of time in port or comparing a port's import container throughput per unit of import container time in port to a port's export container throughput per unit of export container time in port. By doing so, port managers avoid the problem of having to convert container throughput for types of containers other than 20 footers into TEU throughput.

Rather than by type of container and total time in port, comparisons could also be made by the type-of-container throughput per unit of type-of-container time (movement, storage waiting and other-than-storage waiting) in port. Each type-of-container throughput per unit of type-of-container time in port may also be described as a distinct interchange service provided by the port. Consequently, a container port may be viewed as a multi-output port, providing a number of container interchange services. Further, the

theory of multi-output firms may be used as a basis for evaluating container ports, especially from the perspective of costs, e.g., with respect to economies of scope.

6. Conclusion

The output of container ports has generally been measured by its TEU throughput, the number of TEUs that pass through the port from one carrier to another. However, a container port does not produce TEUs but rather provides interchange service for the TEUs that it receives from carriers. Thus, carriers must be willing to provide the port with containers and the port must be willing to interchange these containers from one carrier to another. A drawback to TEU throughput as a container port output measure is that a container port physical output production function with TEU throughput as its output can not be rewritten so that TEU throughput is a production function of the container port's operating options and TEUs provided by carriers. Also, an increase in a container port's TEU throughput does not necessarily imply a decrease in the port's technical inefficiency.

As opposed to TEU throughput, an increase in the container port output measure, TEU throughput per unit of TEU time in port, can be rewritten so that this output measure is a service output production function of the container port's operating options and TEUs provided by carriers. Also, an increase in TEU throughput per unit of TEU time in port in the short-run time period (for which port infrastructure is fixed) implies a decrease in the port's technical inefficiency. This output measure is consistent with measurements utilized by container port managers for investigating reductions in technical inefficiency

at their ports – e.g., the measures, ship loading and unloading service rates and storage time per TEU stored.

The time that TEUs are in port can be obtained from RFID sensors that are attached to containers. Container throughput per unit of container time in port can be computed for each type of container (20 footer, 40 footer, 45 footer and 53 footer) handled in port as opposed to only computing a port's TEU throughput per unit of TEU time (for which container sizes other than a 20 footer would have to be converted into TEUs) and for each type of container time (movement, storage waiting and other-than-storage waiting) in port.

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