CONTAINER PORTS IN COUNTRY SYSTEMS: CALIBRATION OF THE AGGREGATE FUNCTION FOR THE TIME OF THE SHIP IN PORT

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ABSTRACT

The maritime transport of goods has always been the crucial element of international trade. The two pillars of maritime transport are: the sea routes and the port systems. The main characteristic that represents the performance of the ports, in sea side, is the time of the ship in port from the arrival and entrance in the port, to the departure from the port, after having completed the loading/unloading operations. The time of the ship in port, by considering the largest ports of a country, is therefore a synthetic indicator of the ability of each country-system to compete in international trade challenges. It is useful to investigate what are the significant characteristics, aggregated at the country level, that determine the average ship time in port at the country level. This analysis is important for planners operating at national level and for technicians and planners who operate within the individual port systems, because it allows to define general policies aimed at improving the performance of the country-system in the global competition, and of the generic port in the competitiveness.

Keywords: aggregated calibration, country systems, port time function, third-generation port, transport system models.

1 INTRODUCTION

The maritime transport of goods was the crucial element of international trade allowing the integration of countries and continents, which took place in the second part of the 20th century and in the first two decades of the twenty-first one. The globalization of national economies has determined a shift to export-oriented policies based on maritime transport. The two pillars of maritime transport are sea routes and port systems. The development of the routes is linked, on the one hand, to the types of ships available and, on the other, to the organization of services on a global scale that can be differently developed in relation to the available ports' supply. As an example, the hub-and-spoke service model can be implemented only if large ports capable of hosting the 24,000 TEU container ships, operating along transoceanic routes, are available. Ports are therefore one of the two pillars and are also the core of new route structures. Their role becomes crucial and the trade capacity on a global scale of the countries depends on performance of country port systems.

In the literature, several attempts have been made to introduce classifications of ports. The difficulty in identifying commonly accepted classifications depends on the complexity and heterogeneity of port systems.

In 1994 UNCTAD [1] introduced the concept of 'generation' and defined the characteristics of three generations of ports. In the literature there is a wide debate about the definition of UNCTAD [2-5] generation. The three generations are briefly recalled, on which there is a general acceptance in the international literature.

First generation ports are ports in proximity of cities, that are part of them. Cities develop where the port is located, that is, the port is born first and then the city, which grows in

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symbiosis with the port [6,7]. Cities are fed by ports and urban productions are sent to other cities through ports [8,9]. The ships that arrive in this port, were initially promiscuous, both freight and passengers, while today they are dedicated according to the two types of demand.

Second generation ports are ports that develop with the great industrial systems during the 20th century. The steel, petrochemical and energy industries determine the birth of second-generation ports. The technical characteristics differ from the first-generation ports, due to the different requirements: large yards near the docks, oil terminals with sophisticated security and safety systems, starting points for pipelines and power lines [10,11]. The territorial model is overturned: first the industrial plant is established and then the port is built to serve it. The ships that arrive are specialized; they are today mainly oil and gas tankers.

Third-generation ports are born with the container transport. In the second part of the 20th century, maritime container transport became the most advantageous freight transport service [12]. Container ships allow to simplifying the loading/unloading operations in ports. The increase of ships' size allows the reduction of transport costs. Container ports are born. They have well-defined technical and functional characteristics: long docks, high draft, large equipped squares, gigantic cranes.

Third-generation ports are not only the basis for the container transport; but they are also able to generate added value. This characteristic differentiates them from the ports belonging to the previous generations that are a center of costs, even if optimized. Ports have gained strategic importance as they became crucial nodes in the global supply chain. UNCTAD proposed in 1999 the definition of fourth generation port [13-15], and later formulations of fifth-generation port were proposed in the literature [16-18]. The scientific debate is still open on these last two generations [19-22].

Third-generation ports are object of interest of scientific researchers, as far as concerns two main territorial elements: the port areas, which are important for handling and transportation operations; the port hinterland where activities could establish, increasing the added value of goods in transit through ports.

As far as concerns the two above territorial elements of third-generation ports, a specific study was conducted on a large European hub port. The limits and weaknesses of port areas and the general actions to be implemented to reduce the costs of a third-generation port were identified in [23-24]. The external and internal components of the examined port that can support its growth were analyzed. The external components, both those generated by the relationship with the territory and those generated by the relationship with the research centers, have been studied respectively in [25] and [26]. The internal components, concerning the three industrial sectors connected with the third-generation ports (logistics, mechanics and agri-food) were analyzed in [27-29]. It emerged that in many countries, especially in less-developed areas, it is necessary to implement specific national, or local, policies that allow ports to become a value-added generator. One policy, largely implemented with success, is the Special Economic Zone (SEZ) near port areas. A recent study identified the activities that SEZ can activate in order to make port areas more attractive in line with a sustainable development. The study has examined the territorial attractiveness [30], modeling the aggregate economic impact [31] and the disaggregated one [32], verifying therefore the impact that the system of higher education and research can have for the SEZ development [33]. An interesting study compares some aggregate characteristics of the different country systems, from which it emerges that higher times are necessary to export goods to many developed countries [34]. The study presented in [35] showed relevant differences on times connected to the export/import of goods for countries having similar technical-administrative structure and belonging to the same economic-political area. It is emblematic the case of Europe where the time connected to the export of goods has high variance among countries respect to the average value of 10 days.

On the basis of [35], the Italian Presidency Council on Ministers presented an analysis of times connected to export issues, disaggregating them into documentation times, customs times, handling and transport times [36]. A summary is proposed in Table 1, where it emerges that customs times are similar for all countries, while documentation and handling times considerably differ. It is particularly useful to investigate these times because they constitute one of the main elements for the definition of the export capacities of each country. Specifically, it is necessary to deepen the ship times in port because they are an important element for the port choices of shipping companies and directly affect transport costs of containers. It is worth noting that the documentation and customs times depend on the administrative organization of the country and not on the ports' organization.

The main characteristic that affect port on the sea side, is the time of ships in the port, from their arrival and entrance in the port, to their departure from the port, after having completed the loading/unloading operations. Ship port time, by considering the largest ports of a country, is therefore a synthetic indicator of the performance of each country-system to compete in international trade challenges.

The first research question that arises is: which are the main country attributes that affect the average ship port times at country-level? The reply to this question implies a careful analysis of the different databases available at international scale.

The second research question is: is it possible to calibrate a function that relates the average port times of container ships at country-level to country attributes?

Two different approaches are present in the literature to model the above relationship: aggregated and disaggregated [37]. The most common models for the estimation of generalized cost functions, in this case ship time, are statistical-descriptive; which estimate demand

Table 1: Times connected to export operations in different EU and Mediterranean countries (source: [35]).

	Time [days]				
	Documentations	Customs and checks	Handling and transport	Total 2014	Total 2012
Netherlands	4	1	2	7	6
Cyprus	3	1	3	7	7
Germany	4	1	4	9	7
Belgium	3	1	5	9	8
Spain	5	1	4	10	9
France	4	1	5	10	9
Morocco	6	1	4	11	11
Egypt	7	1	4	12	12
Greece	11	1	4	16	20
Italy	11	2	6	19	20

levels through functional relationships with service level and economic-territorial attributes [38,39].

The objective of the paper concerns the analysis and evaluation of ports' performances, according to quantitative indicators that link some country characteristics with the average port ship times at country-level. According to the general objective and to the above research questions, the paper is structured as follows. Section 2 presents synthetically the method used to calibrate the port ship time function, and the attributes that can be used for the model specification, accessible in large international databases. Section 3 presents the results of the model calibration, by discussing the meaning of the calibrated parameters. Finally, some conclusive elements are highlighted and development prospects for work are discussed. The study of the main characteristics that affect ports ship times at country-level is useful for planners operating at national level, because it allows to identify and eliminate the critical issues in order to improve country's competitiveness in global trade. The study is equally useful for technicians and designers who work within individual port systems, because it allows to compare the characteristics of a single port with the average country values.

2 MODEL SPECIFICATION

The model considered put in relation the average port ship times, dependent variable, with different attributes, independent variables, at country-level. The link is supposed to be one-way cause-and-effect, that is, explanatory variables affect the dependent variable. The model is estimated using the least squares method. The next paragraphs present the basic formulation of the method and, then, the attributes used for the specification.

2.1 Method

The general functional form of the model is the following:

$$y = f(\mathbf{x}; \boldsymbol{\beta}) + e \qquad \text{Equation (1)}$$

where

$\mathbf{x}$, is the vector of independent variables (or attributes)
y, is the dependent variable
$\boldsymbol{\beta}$, is a vector of unknown parameters
$f()$, is a function
e, is the error.

Given model (1), it is assumed that $f()$ is linear,

$$y = \beta_0 + \Sigma_{j=1,k}\, \beta_j x_j + e \qquad \text{Equation (2)}$$

where β_0 and β_j are parameters of vector $\boldsymbol{\beta}$.

Model (2) is called multiple linear model. The vector of parameters, $\boldsymbol{\beta}$, is estimated by means of the least squares (LS) method. LS operates by choosing, among the infinite possible lines, the one that minimizes the sum of the squares of the deviations between the values observed and the values estimated by model (2) the vector $\boldsymbol{\beta}$, that is, the one for which it results:

$$\boldsymbol{\beta}_{LS} = \text{argmin}\ \Sigma_{i=1,\,n}\, e^2_i = \Sigma_{i=1,.n}\, (y_i - (\beta_0 + \Sigma_{j=1,k}\, \beta_j x_{j,i}\ ))^2 \qquad \text{Equation (3)}$$

with

$\boldsymbol{\beta}_{LS}$, vector of parameters that minimizes eqn (3)
e_i, observed deviations for each country *i*
y_i,average ship port time observed for the country *i*
$x_{j,i}$, attribute j observed for country *i.*

It is useful to calculate a multiple correlation index, denoted by R^2, which measures the intensity of the linear link between the dependent variable y and the vector of explanatory variables, **x**. The R^2 index is equal to:

$$R^2 = 1 - RSS/TSS \qquad \text{Equation (4)}$$

where

$RSS = \Sigma_{i=1,\,n}\, (y_i - (\beta_0 + \Sigma_{j=1,k}\, \beta_j x_{j,i}\ ))^2$, is the residual deviance*;*
$TSS = \Sigma_{i=1,\,n}\, (y_i - \underline{y})^2$, is the total deviance;
$\underline{y}$ is the average value of the dependent variable.

To consider the number of parameters used in each estimated model, it is useful to calculate the adjusted multiple correlation coefficient, denoted by $\underline{R}^2$:

$$\underline{R^2} = 1 - \left(n-1\right)/\left(n-k-1\right)\ RSS/TSS \qquad \text{Equation (5)}$$

where:

n is the number of observations;
k is the number of attributes.

2.2 Attributes

The model aims to estimate the role of different attributes, aggregated at country-level, in the determination of the average Port Ship Time, PST, aggregated at country-level, which represents the average port time between all ports and between all ships of a ‘Country-System’. This term embraces the role of several characteristics of a country. It is evident that every country has high performance port, compared to the average value, in terms of ship times and less performing ports. The attention is focused on the overall performances of a country considered as a homogeneous system.

The model specification considers two macro-classes of attributes for estimating the value of the average PST:

- transport;
- economic and technological.

The transport attributes can be aggregated into three classes:

- Ships, attributes of container ships related to the country;
- Infrastructures: infrastructural equipment of the ports of the country;
- Services: maritime transport services of the country.

The attributes belonging to class Ships are the following.

- *Average Gross Tonnage of container ships [AGT],* measured in Gross Tonnage: which indicates the average gross tonnage of container ships using country's ports during the period considered (year).
- *Maximum Gross Tonnage of container ships [MGT],* measured in Gross Tonnage: which indicates the maximum gross tonnage of the container ship that used at least one time one of the ports of the country during the period considered (year).
- *Average Capacity of container Ships [ACS],* measured in TEU/10^3, which indicates the average capacity of container ships using country's ports during the period considered (year).
- *Maximum Capacity of container Ships [MCS],* measured in TEU/10^3, which represents the maximum number of TEUs carried by a container ship using country's ports during the period considered (year).

The attributes belonging to class Infrastructures are the following.

- *Linear Shipping Connectivity Index [LSCI]*, with extremes of variability [0–100], which indicates the level of integration of a country inside the global maritime transport network.
- *Logistics Performance Index [LPI],* with extremes of variability [1-5], which evaluates countries based on their efficiency of handling goods both inside and outside the country.
- *Ports Infrastructure Index [PII]* with extremes of variability [1-7], which assesses the quality of the country's port infrastructure over a reference period (year).

The attributes belonging to class Services are reported in the following.

- *Number of Ship Calls [NSC],* which indicates the number of port calls during the examined period by all ships in all ports of the country.
- *Throughput [THR],* measured in TEUs/10^6, which indicates the number of handled containers in a country during the period considered (year).

The attributes related to country are aggregated into two classes Technology and Economy.

The attributes belonging to class Technology are the following.

- *Technology-Overall Index [TOI],* with extremes of variability [0-1], which estimates technological capabilities of a country in relation to physical investment, human capital and technological effort and represents national capacities to use, adopt and adapt new-generation technologies.
- *ICT Technology Index [ITI]* with extremes of variability [0-1]: estimates technological capabilities in a similar way to TOI but only with respect to ICT technologies.

The attributes belonging to class Economy are the following.

- *Gross Domestic Product [GDP]*, which indicates the average annual growth of total GDP as a percentage of the country under consideration.
- *Gross Domestic Product per Capita [GDC],* which indicates the average annual growth of GDP (Gross Domestic Product) per capita as a percentage.

Table 2 shows the attributes considered with the bibliographic references to the database from which they were extracted with the reference year, and the countries that have the maximum and minimum values of the attribute.

3 MODEL CALIBRATION

The model was calibrated using the LS method, as reported in section 2.1. A preliminary, internal, correlation analysis between the variable PST, and the attributes presented in section 2.2, and between the above attributes was carried out. The correlation analysis showed that the attribute maximum capacity of container ships, MCS, is highly correlated with the examined variable average port ship time, PST. Moreover, it is of particular interest to study the impact of ICT dotation of the country, through the attribute ICT-Technological index, ITI, on the variable PST. For the above reasons, the two attributes were considered as the basis for all the specified models. Different models were then calibrated by considering the attributes MCS and ITI as a reference basis, and adding each time one more attribute defined in section 2.2.

Table 3 shows the values of the calibrated parameters, $\boldsymbol{\beta}$, estimated in each model and the values of R^2 and $\underline{R}^2$.

It is recalled that a positive value of the generic parameter β_j indicates a positive linear dependency between the variable port ship time, PST and the attribute x_j, while a negative value indicates a negative linear dependency, that is, as the value of the attribute increases, the value of PST decreases.

The first notation to be made is of a general order and concerns the sign of the parameters, which is almost always, in line with what is expected.

The basic considerations concern model 1 which can be considered the reference model. The value of β_0=2.56 [days] defines the reference threshold of PST for all countries. The value of MCS parameter (β_{MSC}=-0,10) indicates that PST reduces when the country offers ports able to host large capacity ships, that is, countries with larger and more performing ports. Similarly, PST reduces as the country's technological dotation in terms of ICT increases (β_{ITI}=−0,52). It is worth noting that the ratio between the two parameters is 1 to 5, therefore, investments in physical port infrastructures that allow to potentially increase MSC of 5,000 TEUs causes the same impacts on PST generated by an increase of 20% of ITI, indicating the considerable potentialities reduction of PST by increasing the level of ICT in the country.

In models 2 and 3, both the attributes average and maximum gross tonnage of container ships, AGT and MGT, are introduced, while model 4 considers the attribute average capacity of container ships, ACS. According to the calibrated parameters, as the values of above three attributes grow, the value of PST reduces with a weight of at least an order of magnitude lower generated by a reduction of MCS. It is worth noting that the presence of MGT, given the high correlation with MCS, induces a modification of the sign of MCS parameter.

Models 5 and 6 introduce the attributes LSCI and LPI, which both have a positive sign, thus they may be considered as proxies of ports' saturation. In other words, they may indicate that countries with more connections and more logistics services actually induce container ships to spend more time in ports than average.

Models 9, 10 and 11 introduce attributes that, again, indicate that ports are congested: both directly with the attribute throughput, THR, and indirectly with the economic variables GDP, and GDC. Due to the positive signs of parameters, the attributes may be considered as proxies of ports' saturation due to the considerable amount of trade, as in models 5 and 6.

Table 2: Characteristics of the attributes.

	Transport attributes									Economic and technological attributes			
Classes	Ships			Infrastructures				Services		Technological		Economics	
Attributes	AGT	MGT	ACS	MCS	LSCI	LPI	PPI	NSC	THR	ITO	ITI	GDP	GDC
Unit of M	GT	GT	TEUs/10^3	TEUs/10^3	----	----	----	----	TEUs/10^6	----	----	----	----
Database	*	*	*	*	*	**	***	*	*	*	*	*	*
Min	9.36	19.131	0.876	1.740	6.8	2.0	2.1	0.118	0.18	0.0	0.1	0.0018	523
Country	Tunisia	Tunisia	Tunisia	Tunisia	Gambia	Angola	Venezuela	Libya	Venezuela	Gambia	Gambia	Gambia	Libya
Max	85.8	232	8	24	152.9	4.2	6.5	72.6	0.242	1.0	1.0	21.48	64,671
Country	Saudi Arabia	Belgium, …	Saudi Arabia	Saudi Arabia	China	Germany	SING.	China	China	USA	Sweden	USA	USA

(*) UNCTADSTAT (www.unctadstat.unctad.org); (**) The World Bank (www.worldbank.org); (***) The Global Economy (www.theglobaleconomy.com)

Table 3: Calibrated models.

	UoM	1	2	3	4	5	6	7	8	9	10	11	12
β0	----	2.56	2.47	2.63	2.47	2.44	2.38	2.45	2.55	2.44	2.44	2.60	2.4
AGT	GT		−0.001										
MGT	GT			−0.02									
ACS	TEUs/10^3				−0.011								
MCS	TEUs/10^3	−0.10	−0.08	0.11	−0.08	−0.11	−0.07	−0.082	−0.07	−0.08	−0.08	−0.07	−0.07
LSCI	----					0.01							
LPI	----						0.09						
PII	----							−0.003					−0.04
NSC	----								−0.0015				1.02
THR	TEUs/10^6									0.04			
ITO	----												
ITI	----	−0,52	−0,08	−0,002	−0,0002	−0,012	−0,67	−0,00008	−0,53	−0,01	0,00	−0,7	−0,001
GDP	----										0.01		
GDC	----											0.0027	
R^2		0,60	0,58	0,63	0,58	0,60	0,60	0,58	0,6	0,59	0,58	0,60	0,63
$\bar{R}^2$		0,58	0,56	0,60	0,56	0,57	0,57	0,56	0,57	0,57	0,56	0,58	0,57

Model 7 is interesting because the presence of the attribute port infrastructure index, PII, causes the reduction of the value of parameter associated to ITI attribute and that, even if in modest amount, of the MSC attribute.

Finally, model 12 presents four attributes, in which the attributes PII, and NSC are considered. It emerges that the parameter associated to attribute NSC is positive, if compared to model 8, in accordance with the attributes of models 9, 10, 11, as NSC may be considered as another and different indicator of ports' congestion.

4 CONCLUSIONS

In this work, the study of the representative function of the time of container ships in the ports of a generic country was presented. The average value of times between all ports in a country was considered. Attributes that can be considered as independent variables were analyzed.

Two basic attributes have been identified that determine the value of ship time with a negative linear dependency. The first is the maximum capacity, in TEU, of the ships that can be hosted in the ports a country. The second is the country's ICT technology index.

From the different specifications and calibrations three classes of quite homogeneous attributes may be identified.

A first class that refers to the ships' size that can use the ports of a country, these attributes weigh heavily in determining the average time per country, and reduce it as they grow. The result is interesting because it identifies a better organization of the ports as their infrastructural capacities grow. The result is confirmed by the role of the infrastructure indicator which also has a negative linear relationship.

A second class refers to the aggregate economic characteristics of the country. The attributes of this class have a positive linear relationship, that is, as they grow, the average time increases. This result is also interesting because it indicates that an high utilization of the ports induces on average an increase in ship time.

A third class is composed by attributes that may be associated to the country's performance in terms of logistics services and maritime connections with other countries. These attributes, like those of the second class, have also a positive linear relationship, confirming that their growth indicates a better organization of services, but aggravates port systems that fail to meet this demand well.

Finally, the parameter associated to the infrastructure index has a negative linear dependency with port time that confirms the importance of investments in the port sector.

This work provides an important contribution to the knowledge of the ability of each country system to deal with maritime transport through its access points which are the ports. In the literature, ports are studied as individual systems, while there is no transversal knowledge to all ports of each country, although the overall supply policies and the knowledge of the potential of each country by demand must be based precisely on these overall assessments.

The results obtained allow to planners and technicians of the decision-making departments at national and regional level to implement adequate policies for the improvement of the overall values of the country or region in the performance of the ports that insist in that territory. The results are useful for the technicians of the various port authorities because they allow to build an (average) bench marking with respect to the country and allow to identify in which position the individual port is located. Further developments need to be carried out by analyzing the disaggregated characteristics of individual ports.

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