ICT Factors Affecting Ship Times in Container Ports: Experimental Analysis at Country Level

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Abstract. One of the characteristics of container ports' performances, on the sea side, is the time of ships in port from the arrival and entrance to the departure from the port. The time of the ship in a container 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. The paper presents an experimental analysis aimed to evaluate the incidence of the Information and Communication Technology (ICT) and structural port factors on the average ship time in container ports at country level. Some quantitative indicators are used in the evaluation, such as the calibrated parameters, the substitution rates, the elasticities; the observed vs estimated values.

The results of the experimentation show that the parameters associated with the attributes considered are negative, i.e. the higher is their value, the shorter is the port time. They are interesting for national port systems, because they could support general policies and financial investments on physical and/or digital port infrastructures in order to improve the performances of a national port system in the global competition.

Keywords: commercial ports · ship times in container ports · vessel turnaround time · Information and Communication Technology (ICT) · structural factors · models estimation

1 Introduction

Since ancient times maritime transport has been a vital and strategic factor in the social and economic development of the Mediterranean peoples. It can be said that the history of civilization coincides with the evolution of maritime transport. The innovations in maritime transport played a fundamental role in trade among peoples, reducing the distances among them.

The evolution of ports was classified according to a series of criteria identified by UN Trade and Development (UNCTAD), named as generations [1, 2]. The initial classification of UNCTAD was followed in the later years by an intense scientific debate, a brief summary of which is reported below.

First-generation ports [3–5] were born in ancient times, in proximity to the cities to which they were directly connected. The cities develop where the port is located, that is,

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the port is born first and then the city close it, which grows in symbiosis with the port. Second-generation ports [6] developed after the settlement of large industrial plants after the end of the Second World War. Those ports were built near large industrial areas of steel, petrochemicals, power plants. The territorial paradigm was reversed compared to first-generation ports: initially, the industrial plant was established, and subsequently, the port was built to serve its needs. Third-generation ports [7–9] emerged with the rise of container transport in the final decade of the XX century, maritime container shipping definitively became the most competitive transport option.

The transport cost was drastically reduced and port became generators of added value by manipulating the goods in transit. Fourth-generation ports [7–9] are port systems, generally composed of two main ports, in which port stakeholders cooperate creating alliances on market segments, or sharing infrastructures and services. The creation of port systems concurs to the solution of the problem of centrality ports in the maritime service at international scale [10–12]. The drivers of the cooperation are: the alliances between shipping companies, the naval gigantism and the sharing land infrastructures in the port hinterlands. The main characteristic of fifth generation ports [13, 14] is the use of emerging Information and Communication Technology (ICT) in the interaction among the port stakeholders. Their introduction has shown that ICT is a further pillar of port competitiveness, such as the position near a city or an industrial plant, the capacity to generate added value, the shared infrastructures and services. A tool that enhances interaction among port stakeholders is the Port Community System (PCS), which has been largely studied in recent years in order to assess its benefits, particularly in increasing the utilities of port operations.

In the above context, the paper presents the results of an experimental analysis of container ship port times, also called vessel turnaround time, in the potential fifth-generation ports. The focus is on the overall performance of a country's port system. Although some papers have been published on the topic of ship turnaround times (see [15, 16]), the paper examines the interplay between the maximum capacity of the container ships, the dotation of ICT infrastructures, and the number of port calls.

The results of the experimentation show that the parameters associated with the attributes considered are negative, i.e. the higher is their value, the shorter is the port time. Furthermore, the results of the substitution rates between the two types of factors, ICT and infrastructural, and the elasticities of the individual attributes on port time are particularly interesting. They could support general policies and financial investments on physical and/or digital port infrastructures in order to improve the performances of a national port system.

The remaining part of the paper is structured as follows. Section 2 presents the characteristics of the fifth generation ports, focusing on the role of Port Community Systems (PCS). Section 3 reports the specification of indicators to evaluate the incidence of different factors, both ICT and infrastructural, on the values of ship times in container ports. Section 4 reports some experimental results of the specified indicators calculated on a set of countries. Finally, the discussion and the research perspectives.

Author Proof

2 Fifth-Generation Ports: The Role of the Port Community Systems (PCSs)

Fifth generation ports are characterized by horizontal and vertical integration among the port stakeholders, that it is possible by means of emerging ICT technologies such as Internet-of-Things (IoT), Artificial Intelligence (AI), blockchain, big-data, digital twin. The emerging ICT technologies in ports are one of the pillars of ports competitiveness, together with their position close to the city or to industrial plants; the capacity to generate added value in the port hinterland; the cooperation among stakeholders [13, 17, 18].

Today financial and information transactions in ports are generally supported by the adoption of stand-alone ICT systems, sometimes vertically integrated. They increase the efficiency operations of the single private stakeholder, or of the single public service, but do not resolve the interactions between different stakeholders. Interactions between stakeholders are relevant to facilitate the three main flows present in the port: goods, information and financial. The cargo flow relies on data exchange to optimize port operations (e.g. dock and yard operations) for thousands of containers.

The traditional approaches generate low capacity utilization of ships and port infrastructures, that have reflections of ship times. The information flow id mainly related to authorization operations: the paper-based solutions represent a strong constraint for international banks, as defined by the Logistics Performance Index, especially in ports (The World Bank, 2014). The potentialities offered by emerging ICT may be emphasized by means of the Port Community Systems (PCSs) [17, 19–21]. PCSs increase the cooperation among the port stakeholders, and consequently increase their competitiveness as a community compared to other ports. The cooperation is possible due to the integration of procedures and the sharing of information and documents.

3 Ship Times in Container Ports: Specification of Indicators

It is recalled firstly that the general function average ship time in port, t, belongs to the class of functions formalized in (Eq. 1). The function presents a structure commonly used to calculate the transport costs on the elements (e.g. links) of a road network and it is studied in the different load conditions of the links: un-congested and congested (see [22, 23]).

The general function for ship time in port is the following:

$$\mathrm{t} = \mathrm{t}_0 + t(\mathrm{f}/\mathrm{Cap}) \tag{1}$$

where

t_0, average ship time in free-flow conditions, or when there is no congestion in port on the seaside;

$t()$, function;

f, ship flow arriving at the port (e.g. ship/day);

Cap, port capacity, or maximum value of ship flow serving at the port (e.g. ship/day).

The following statistical indicators have been considered in the analysis presented in this work:

(a) calibrated parameters
(b) substitution rate
(c) elasticity;
(d) observed vs estimated values of ship time in ports.

a. Calibrated parameters

The experimental model presented in [24, 25] concerns the calibration of the aliquot of average ship time in free-flow conditions arriving at the single port, t_0:

$$t_0 = t_0\ (\mathbf{x}; \boldsymbol{\beta}) + \varepsilon \tag{2}$$

where

$\mathbf{x}$ is a vector of attributes,

$\boldsymbol{\beta}$ is a vector of unknown parameters;

$t_0()$ is a function;

ε is the error term.

A linear specification of Eq. (2) is the following:

$$t_0 = \Sigma_j\ \beta_j\ x_j + \varepsilon \tag{3}$$

where:

x_j is the generic attribute of vector $\mathbf{x}$;

β_j are components of vector $\boldsymbol{\beta}$.

The vector of unknown parameters, $\boldsymbol{\beta}$, has been calibrated by means of the Least Squares (LS) method, which allows to identify the optimal vector, among the different configurations of $\boldsymbol{\beta}$, that minimizes the sum of the squares of the deviations between the observed values of ship times and the values of ship time calculated with Eq. (3).

b. Substitution rate

The literature on discrete choice models [22, 23, 26] considers the substitution rates between the level-of-service attributes a significant indicators to evaluate the choice behaviour of individuals. Among these, the substitution rate with the monetary cost are particularly relevant. Thus, for example, given the parameters of travel time, β_t, and of the monetary cost β_c respectively, the Value of Time (e.g. in modal choice behaviour) is equal to: VoT = βt / βc, expressed in monetary units per unit of time.

According to the above definitions and extending them to an aggregate context, in general terms the substitution rate may be expressed as:

$$s = \beta_{x1}/\beta_{y2} \tag{4}$$

with

s, substitution rate

β_{x1}, parameter associated to attribute x_1;

β_{y2}, parameter associated to attribute x_2.

c. Elasticity

Elasticity provides information on the percentage change in the dependent variable (port ship time) to the percentage change of one independent variable attribute. The calculation of direct point elasticity related to an attribute x_k is executed for infinitesimal variations and calculated according to the following equation:

$$\varepsilon_k = (\partial t/t)/(\partial x_k/x_k) \tag{5}$$

where

x_k is the value of the attribute k;

t is the value of port ship time.

The calculation of direct link elasticity related to an attribute x_k is executed for finite variations and calculated according the following equation:

$$E_k = (\Delta t/t)/(\Delta x_k/x_k) \tag{6}$$

where

x_k is the value of the attribute k;

t is the value of port ship time.

d. Observed vs. estimated values

The comparison between observed and estimated values of ship time in ports has been used to verify the capacity of the model to reproduce the observed values. There are several indicators to compare the two classes data. In this work this comparison has been executed in a qualitative way by building radar diagrams showing the difference between the estimated and observed value of ship time for a group of selected countries.

4 Ship Times in Container Ports: Experimental Results

The following attributes, among the others, are considered in the experimentation (see [24] for details):

- Maximum Capacity of container Ship (MCS) [TEU/10^3], maximum number of TEUs transported by a container ship touching the ports of the country in the period considered (e.g. year);
- Number of Ship Calls (NSC), [ship/year*10^3], number of port calls in all ports of the country;
- ICT Technology Index (ITI) [0–1], level of ICT equipments of a country.

The values of attributes are obtained from the UNCTADSTAT data-base referred to the year 2019 (unctadstat.unctad.org). Figures 1, 2 and 3 present the scatterplots, respectively, between:

- the average ship time in port and the maximum capacity (MCS) (Fig. 1), where a declining trend appears and a reducing dispersion of ship times for increasing values of maximum capacity;
- the average ship time in port and the ICT Technology Index (Fig. 2), where, also in this case, a declining trend appears and a reducing dispersion of ship times for increasing values of ICT technology Index;
- the average ship time in port and the number of ship calls (Fig. 3), where a quick decline of ship times appears for increasing number of ship calls until a value of 5000 ship/year followed by slightly declining values.

Table 1 reports the maximum, minimum and average values of the examined attributes among the set of examined countries.

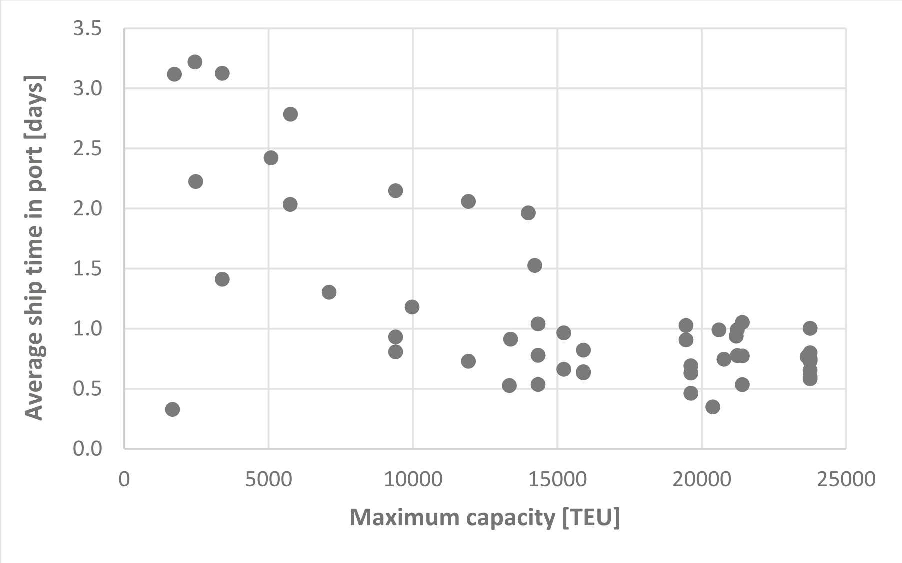

Fig. 1. Scatterplot between average ship time in port and maximum capacity.

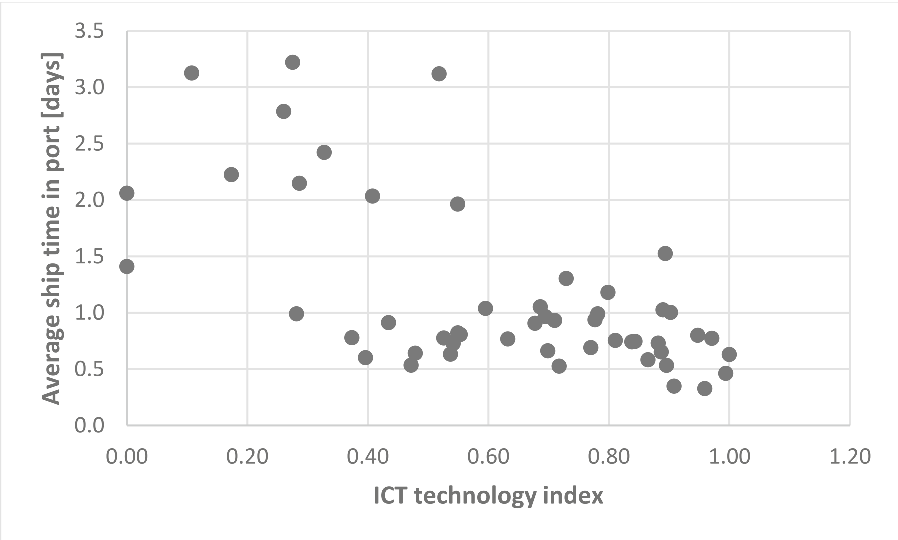

Fig. 2. Scatterplot between average ship time in port and ICT technology index.

4.1 Calibrated Parameters

The model parameters (Eq. 3) were estimated using the LS method [24, 25]. Table 2 shows the values of the estimated parameters, β_j, and the values of r^2 and $\underline{r}^2$.

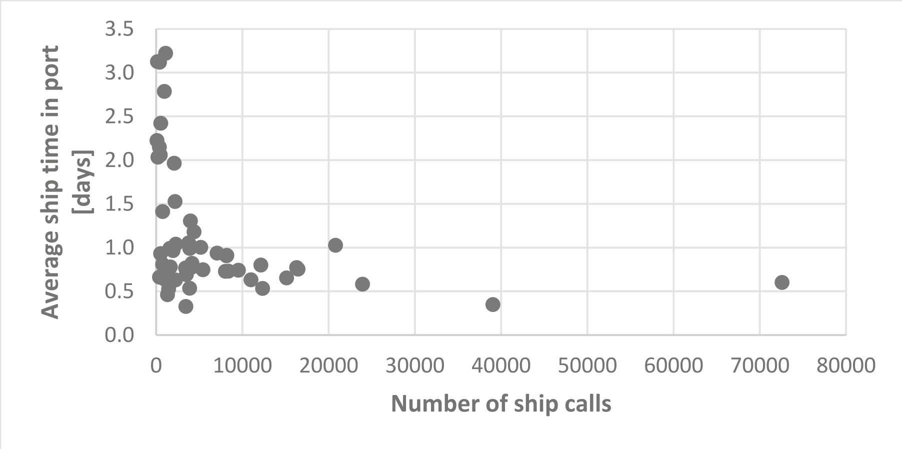

Fig. 3. Scatterplot between average ship time in port and number of ship calls.

Table 1. Maximum, minimum and medium values of examined attributes

		Max	Min	Average
MCS	[TEU*10^3]	23.76	19.46	22.07
NSC	[ship/year*10^3]	72.58	3.78	17.74
ITI	[0,1]	0.95	0.40	0.74

Table 2. Calibrated parameters

	UdM	1	2
β_0	[days]	2.56	2.55
β_{MCS}	[TEU/10^3]	−0.069	−0.067
β_{NSC}	[ship/year*10^3]	–	−0.0015
β_{ITI}	[0,1]	−0.52	−0.46
r^2	–	0.60	0.60
$\underline{r}^2$	–	0.58	0.57

The initial considerations concern the model 1 which can be assumed as the reference model. The value of $\beta_0 = 2.56$ [days] defines the reference threshold of the average ship time in port for all countries. The value of the parameter of the attribute MCS ($\beta_{MSC} = -0.07$) indicates that the average ship time in port reduces when the country id equipped with ports capable of hosting container ships of high capacity. It is important to highlight the sign and the value of the parameter associated to ITI attribute, $\beta_{ITI} = -0.52$. The parameter indicates that the average ship time in port reduces as the country's digital technology equipment increases.

The model 2 introduces the NSC attribute, whose associated parameter is negative. In this case, an increase of the number of ship calls could be associated with a better organization of the country's port system, that leads to reduced average ship times in port. It is worth noting that the parameter associated to the ITI attribute is similar among the two models and, therefore, confirms the role and importance of the country's digital technology equipment.

4.2 Substitution Rate

The substitution rate between the parameters associated with the ITI and MSC attributes, $s = \beta_{ITI}/\beta_{MSC}$, is equal to 7.4 in model 1 and 7.6 in model 2. Therefore, an increase in the value of 0.1 of the ITI attribute corresponds to an increase of between 740 TEUs and 960 TEUs of the maximum capacity of container ships that can potentially be hosted in the ports of a country. The substitution rate between the parameters associated with the ITI and NSC attributes, $s = \beta_{ITI}/\beta_{NSC}$, is equal to 446 [ships/year]. Therefore, an increase in the value of 0.1 of the ITI attribute corresponds to an increase of 446 [ships/year] ship calls in the ports of a country.

4.3 Elasticity

Model 1 and 2 are considered for the calculation of direct link elasticity by means of Eq. (6) for eight countries considering an increase of 5% (=100 Δx_k / x_k) for each attribute. Among the eight countries, two of them belong to the Northern European range: Belgium and The Netherland; four countries belong to the Mediterranean Basin: Italy, Spain, Greece and Morocco. Moreover, China and United States are considered individually. Table 3 presents the values of the estimated direct link elasticities. Considering the average values of elasticity per single attribute, the following elements emerge. Both models are rigid with respect to the attribute ITI: $\varepsilon_{ITI} = 0.61$ for model 1 and $\varepsilon_{ITI} = 0.67$ for model 2, Both models are elastic with respect to the attribute MCS: $\varepsilon_{MCS} = 2.45$ for model 1 and $\varepsilon_{ITI} = 2.64$ for model 2.

Let' consider the individual values of elasticity for each attribute and country. As far as concerns ITI attribute, the models are basically rigid for the Mediterranean countries: the range is from $E_{ITI} = 0.34;0.36$ for Morocco to $E_{ITI} = 0.51;0.53$ for Greece, except for Spain where $E_{ITI} = 1.06–1.19$. The models are elastic for the Northern European countries: the range is from $E_{ITI} = 1.10;1.19$ of Belgium to $E_{ITI} = 1.22;1.37$ for The Netherland. The models are rigid for China ($E_{ITI} = 0.30; 0.37$) and United States ($E_{ITI} = 0.63; 0.69$). As far as concerns MCS attribute, the models are elastic for all the examined countries: the range is from $E_{MCS} = 1.61;1.67$ of Italy to $E_{MCS} = 4.11;4.54$ for The Netherland. As far as concerns NCS attribute, model 2 is highly rigid for all the examined countries: the range is from $E_{NCS} = 0.02$ of Italy and Belgium to $E_{NCS} = 0.19$ of China.

4.4 Observed Vs. Estimated Values of Ship Times

The results of the comparison between observed values of attributes (see Figs. 1, 2 and 3) vs. estimated values of attributes by means of models 1 and 2 is graphically presented

Table 3. Link elasticity of models 1 and 2 vs. increases of attribute of +5%

	Country	Model 1		Model 2		
		ITI	MCS	ITI	MCS	NCS
Increment 5%	Italy	−0.42	−1.61	−0.44	−1.67	−0.02
	Belgium	−1.10	−3.89	−1.19	−4.15	−0.02
	The Netherland	−1.22	−4.11	−1.37	−4.54	−0.05
	Spain	−1.06	−3.81	−1.19	−4.22	−0.06
	Greece	−0.51	−2.13	−0.53	−2.20	−0.01
	Morocco	−0.34	−1.86	−0.36	−1.91	−0.01
	China	−0.30	−2.41	−0.37	−2.93	−0.19
	USA	−0.63	−1.85	−0.69	−1.99	−0.05
	Average value	*−0.61*	*−2.45*	*−0.67*	*−2.64*	*−0.05*

in the radar diagrams of Figs. 4 and 5. The following elements may be highlighted. In both models the estimated values are lower than the observed ones.

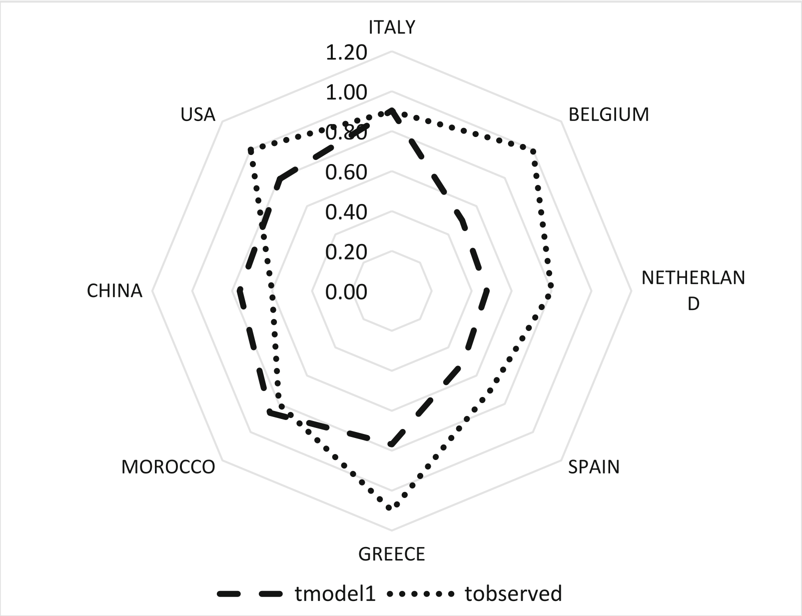

Fig. 4. Comparison between observed and estimated values of ship time in port (days): radar diagrams for model 1.

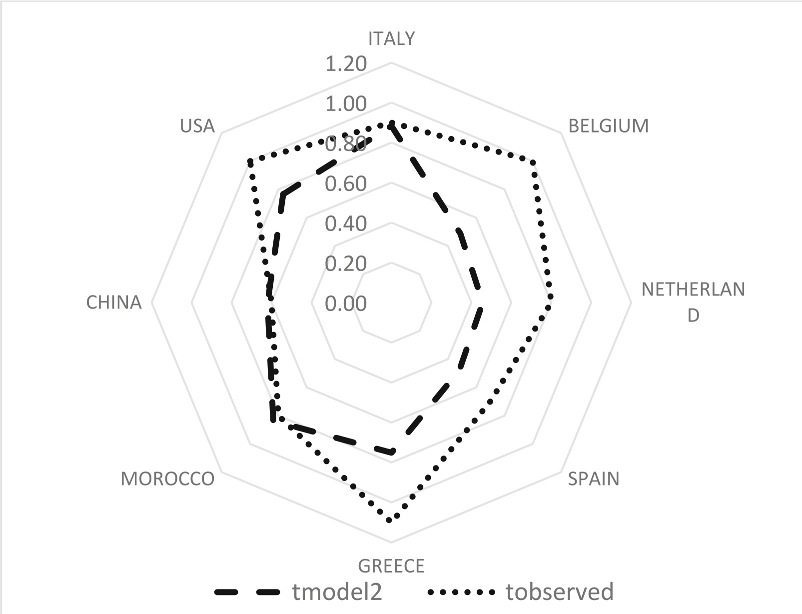

Fig. 5. Comparison between observed and estimated values of ship time in port (days): radar diagrams for model 2.

5 Discussion and Further Research

The performances of container ports are characterized, on the sea side, by the time of ships in port, which may be considered as a synthetic indicator of the capacity of a national port system to compete in the international trade.

The paper investigates the factors belonging to two main categories that generate impacts on ship times in container ports. The first factor belongs to the category of physical (material) components and the second one to the category of intangible (or immaterial) components. In particular, an experimental analysis has been executed to evaluate the incidence of the structural and ICT port factors through some quantitative statistic indicators: calibrated parameters, substitution rates, direct elasticities; observed vs estimated values.

The calibration of the parameters shows that a reference lower threshold of 2.56 days may be assumed as average ship time for the ports of the examined countries. If a country has ports equipped to handle container ships of higher capacity, the ship time reduces. This attribute could be considered as a proxy of the infrastructural dotation of a country in terms of container ports, that allow better performances in handling container ships on the seaside. Moreover, the average ship time decreases for countries that present a higher ICT dotation. This aggregate result is in line with some disaggregate studies about the role of emerging ICT in facilitating the interactions among port stakeholders and, therefore, increasing their shared utility [13].

The calculation of the substitution rates could provide an interesting insight on costs of investments in container ports regarding physical and digital infrastructures. According to the estimated values, national investments in digital technology that increase the ITI attribute of 10% (ΔITI = +0.1) determine a fallout in container ports of the following order of magnitude. On the side of maximum capacity of ships, an increase of 1000 TEU in the average size of container ships that can be hosted (for example in Italian ports). On the side of number ship calls, an increase of 446 ships/year handled in ports. It is worth noting that the dredging costs to deepen the port seabed in order to host ships of higher dimensions (ΔMCS = +1000 TEUs) could be estimated in at least 50 million euros per port. Such an intervention, for example, on the twenty container ports operating in Italy would entail an expense of one billion euros.

The estimated values of direct elasticities per single attribute lead to the following considerations. The models are, on average, rigid with respect to the ICT attribute and elastic with respect to the infrastructural attributes. The values of elasticities for single countries do not provide clear indications, and they need to be further investigated.

The comparison between observed and estimated values of ship times show that the estimated values are generally lower than the observed ones.

Further developments are necessary on two main research directions. The first direction concerns the investigation about the influence of further ICT attributes in order to evaluate the impacts of different generations of PCS. The second direction regards the comparison with the results of other theoretical approaches, like network models and time series models.

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