Saint Petersburg State University
Graduate School of Management

An empirical study of Russian container terminals' handling capacity on the basis of production frontier approach

Master's Thesis by the 2nd year student
Master in Management - CEMS
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ЗАЯВЛЕНИЕ О САМОСТОЯТЕЛЬНОМ ХАРАКТЕРЕ ВЫПОЛНЕНИЯ ВЫПУСКНОЙ КВАЛИФИКАЦИОННОЙ РАБОТЫ

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Описание цели, задач и основных результатов	Цель исследования: разработка и применение аналитических моделей для измерения влияния инфраструктурных характеристик на пропускную способность контейнерных терминалов. Задачи работы: операционализация понятия пропускной способности; сбор эмпирической базы данных; определение инфраструктурных характеристик, влияющих на пропускную способность; моделирование взаимосвязи между грузооборотом и инфраструктурными характеристиками; построение модели производственных границ для оценки пропускной способности; оценка технической эффективности и расчет эмпирической пропускной способности контейнерных терминалов; сравнительный анализ результатов; моделирование взаимосвязи между технической эффективностью терминалов и инфраструктурными характеристиками. Результаты: построена модель взаимосвязи между грузооборотом и инфраструктурными характеристиками, интегрированными в предложенный индекс качества инфраструктуры. Оценена эмпирическая пропускная способность и техническая эффективность терминалов. Получена модель прогнозирования эмпирической пропускной способности контейнерных терминалов в соответствии с их инфраструктурными характеристиками.
Ключевые слова	Контейнерные терминалы, номинальная пропускная способность, фактическая (эмпирическая) пропуская способность, граница производственных возможностей, техническая эффективность, SFA

ABSTRACT

Master Student's Name	Anna A. Provotorova
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Faculty	Graduate School of Management
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Academic Advisor's Name	Yury V. Fedotov
Description of the goal, tasks and main results	Research goal: the study is aimed to make a design and application of analytical models for measuring an impact of the infrastructural variables on the container terminals handling capacity. Research objectives: operationalization of the concept of container terminal's handling capacity; collection of relevant empirical database; identification of container terminal infrastructure variables influencing handling capacity; modeling of relationship between throughput of the container terminals and their infrastructure variables; estimation of alternative production frontier models for container terminal's handling capacity; calculation of technical efficiency and empirical capacity for container terminals; comparative analysis of the results; analysis of relation between technical efficiency of the terminals and the infrastructure variables. Results: the causality model of relationship between throughput of the container terminals and their infrastructure variables was provided. For this purpose the infrastructure quality index was proposed. The empirical container handling capacity and technical efficiency rates for selected container terminals were estimated. The model for forecast of empirical container terminal handling capacity according to infrastructure characteristics was obtained.
Keywords	Container terminal, nominal capacity, empirical (handling) capacity, production frontier, technical efficiency, SFA

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Introduction

Relevance of the study

More than 90% of world trade is carried by sea transport. Therefore, ports are the strategic infrastructure facilities and the basis of international trade, they plays a key role in international logistics chains and acts as trade facilitators in the regions and countries.

During the last decades the containerized trade volumes experienced a sharp rise from 224 million TEU in 2000 to 793 million TEU in 2018 because of the ability to containerize different type of goods. It led to the establishment of new container terminals on the main trade routes and as a consequence, increase in the fierce competition for customers with neighborhood terminals.

Aware of that facts, the port authorities showed great interest in effective port management. Thus, they are constantly looking for strategies to meet growing needs through the rational utilization of their current resources. Port efficiency is an indicator of an appropriate port development and right management decisions, and therefore monitoring and comparing one port with other ports in terms of their efficiency has become an integral part of competitive analysis in many countries.

If the container terminals could properly conduct the evaluation of their performance in terms of the track of operational efficiency change in their activities, it would generate valuable information for terminal management for their further steps in the strategy development or in resource utilization.

Managerial problem

Due to the change in the demand for certain type of cargo, there are a decrease in the throughput flow in ports which are dependent on non-container cargo. Therefore, the management faces the tough long-term challenge to increase the throughput flow in these ports with falling demand on the main cargo of the port. One of the possible solution is to re-profiling the port into container terminal, since there is a long-term trend of containerization of goods, and there is also a lack of container handling capacity at current ports in Russia in a short term. Therefore, the relevant task of this study is to define what infrastructure characteristics a terminal should possess in order to be re-profiled.

Research gap

Although many studies have already analyzed the technical efficiency of container terminals using different set of variables and on the various geographical scope, most of them were focused on the general performance analysis of container terminals and horizontal comparison of estimated efficiency scores among selected observations. In addition to that, examined articles are ended up with the identification of the drivers which impact the technical efficiency and no further research was made. After thorough analysis of academic papers, no study has been found that identified the infrastructure variables which influence the handling capacity of the terminal. Therefore, this research is aimed at filling this gap by proposing the infrastructure characteristics which impact the handling capacity of the container terminal. Moreover, the decision support tool for the authorities of container terminals will be proposed which defines the parameters of terminal's infrastructure characteristics needed for the reaching certain empirical capacity of the terminal.

Research goal and objectives

The study is aimed to make a design and application of analytical models for measuring an impact of the infrastructural variables on the container terminals handling capacity.

In order to cover research gap and meet the research goal the analysis of port efficiency concept should be conducted. According to the issues investigated in the frame of port efficiency, the following objectives are set:

1. Operationalization of the concept of container terminal's handling capacity;
2. Collection of relevant empirical database;
3. Identification of container terminal infrastructure variables influencing handling capacity;
4. Modeling of relationship between throughput of the container terminals and their infrastructure variables;
5. Estimation of alternative production frontier models for container terminal's handling capacity;
6. Calculation of technical efficiency and empirical capacity for container terminals;
7. Comparative analysis of the results;
8. Analysis of relation between technical efficiency of the terminals and the infrastructure variables.

Research questions

In order to meet the research objectives stated above, the following research questions should be answered:

1. What is the relationship between container terminal's handling capacity and infrastructure variables?
2. What should be understood under container terminal handling capacity concept?
3. What are container terminal infrastructure variables influencing handling capacity?
4. What is relationship between technical efficiency of terminal handling capacity and its infrastructure characteristics?

Research design

Stage 1. Operationalization of the container terminal handling capacity concept and identification of container terminal infrastructure variables influencing handling capacity;
Stage 2. Causal modeling of relationship between the container terminal throughput and its infrastructure variables;
Stage 3. Construction of the alternative production frontier models;
Comparative analysis of technical efficiency of the container terminals handling capacity;
Stage 4. Investigation of relationship between technical efficiency of terminal handling capacity and its infrastructure characteristics.

To answer the questions raised above and meet the goals that were set, quantitative methods would be used. Among them, the cause and effect analysis will be conducted for the modeling of relation between throughput of the container terminals and their infrastructure variables. Then the production technology modeling will be made in order to construct the alternative production frontier. After that, production frontier analysis should be made for the comparative analysis of the technical efficiencies. Lastly, the model of relation between technical efficiency of the terminals and the infrastructure characteristics would be estimated.

CHAPTER 1. RESEARCH CONTEXT

1.1 Container Ports and Terminals

1.1.1 Overview of container market

The objective of this chapter is to give an overview of the container transport logistics and the place of container ports and terminals in this chain as well as to describe typical operation function on the container port or terminal. Containerization was a key factor which was responsible for the facilitation of the global trade. Looking to the figure 2.1, it may be seen the dramatic increase in global economy which was followed with the container implementation on the market[1]. The commercial usage of containers started in 1966 when the fast growth of global economy was faced[2].

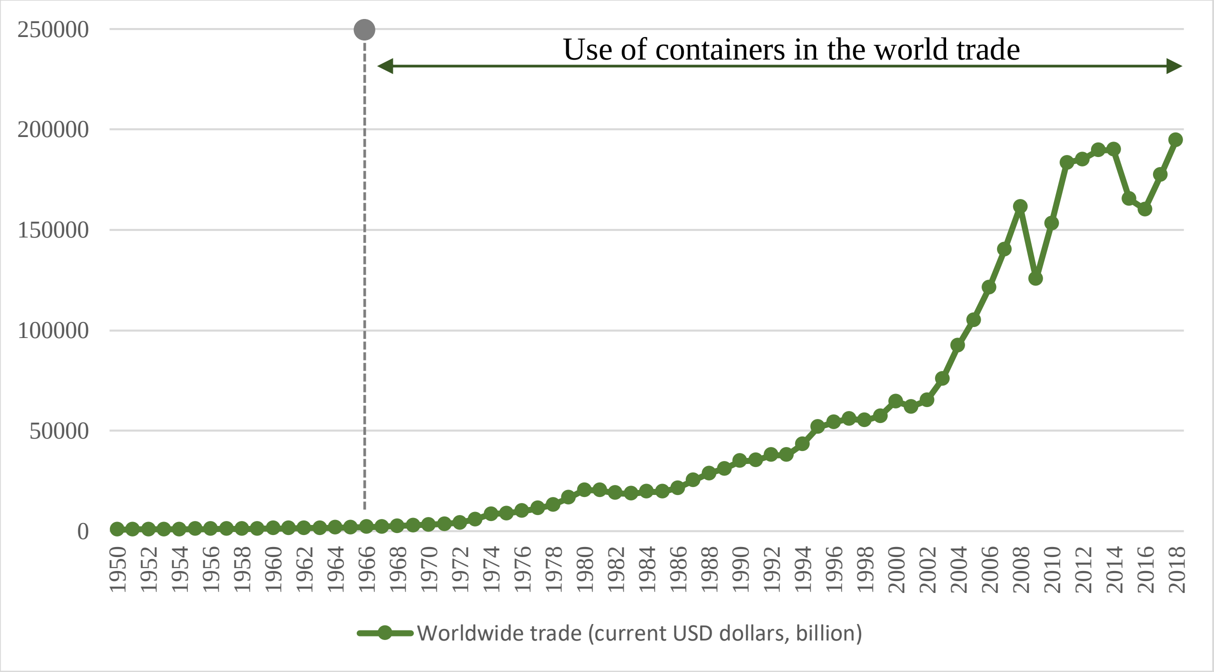

Figure 1.1 World trade, 1950-2018

Source: UNCTAD

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[1] Connecting to compete 2018 : trade logistics in the global economy - the logistics performance index and its indicators (English). Washington, D.C. : World Bank Group. Retrieved June 4, 2020, http://documents.worldbank.org

[2] Bernhofen, D.M., El-Sahli, Z., Kneller, R. (2016). Estimating the effects of the container revolution on world trade. Journal of International Economics, Vol. 98, 36-50

From the past 20 years container seaborne trade has increased by 3 times with 6,4% CAGR reaching approximately 17% of total seaborne trade[3].

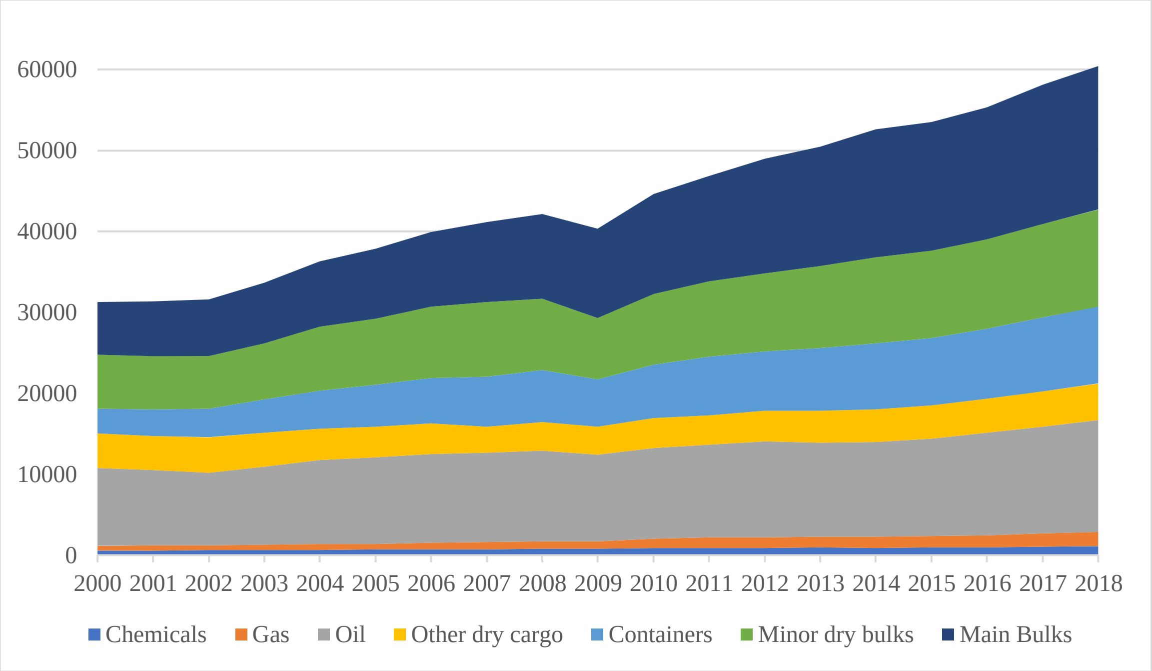

Figure 1.2 World seaborne trade in cargo ton-miles, 2000–2018 (Billions of ton-miles)
Source: UNCTAD

According to UNCTAD, it is proved that there is a high correlation between seaborne trade, GDP growth and industry activity. Moreover, container port traffic reflected the development of world GPD and repeats its ups and downs, which may be seen on the figure 2.3. For example, since 2008 there had been an impressive growth of containerized goods flow up to 10% annually, this figures outrun the growth of the worldwide trade and seemed very promising in the future. But financial crisis in 2008 and following recession decreased the demand for consumer goods which were transported mainly in containers and container flow dropped by 9% in 2008. In 2010 it recovered with the new strongest growth rate of 12,9% which can be explained by the increase of consumer goods from Asia, namely facilitation of trade between Europe/ North America and Asia. Then 2015 and 2016 were difficult years for cargo flows which were caused by the decrease in Europe-China trade, slowdown of China development[4]. Although, container flow continued to show the grow with positive rate. Now UNCTAD is expecting that containerized trade is going to grow with 6% annually until 2023[5].

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[3] UNCTAD, (2017). United Nations Conference on Trade and Development secretariat. Review of Maritime Transport 2018, United Nations publication. Retrieved June 4, 2020, from https://unctad.org/

[4] Full Year Results (2018). Global Ports. Retrieved from June 4, 2020, https://www.globalports.com/en/investors/reports-and-results/

[5] UNCTAD, (2018). United Nations Conference on Trade and Development secretariat. Review of Maritime Transport 2018, United Nations publication. Retrieved June 4, 2020, from https://unctad.org/

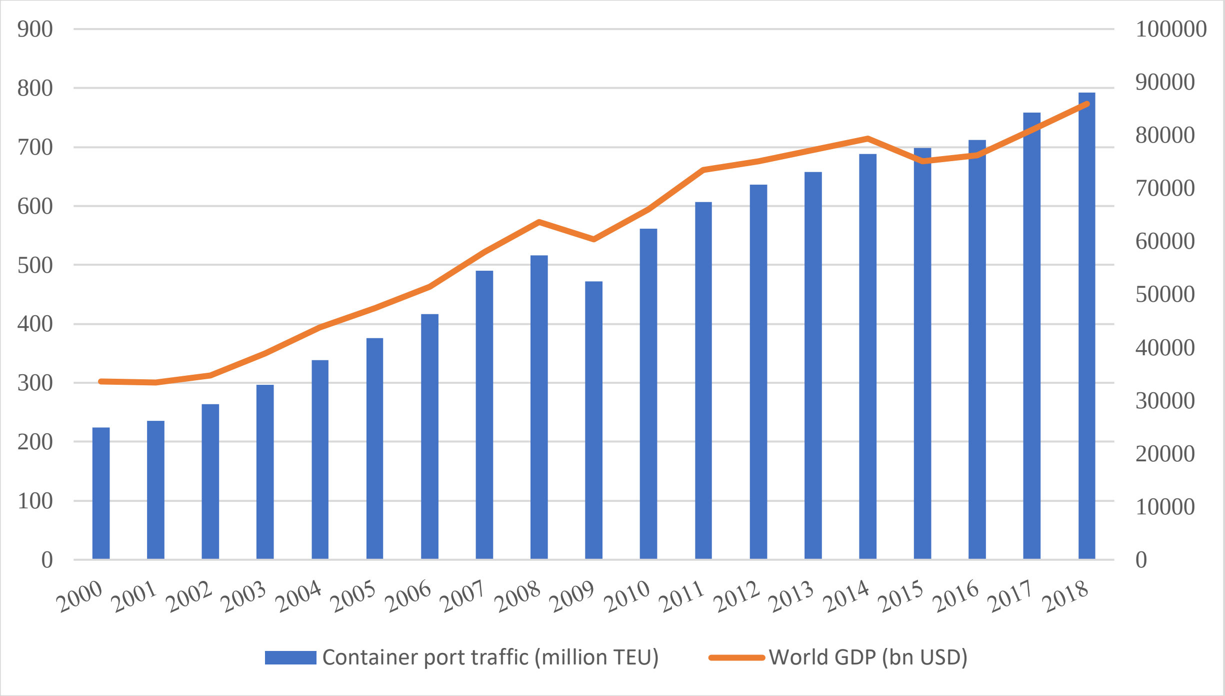

Fig. 1.3 Container port traffic and world GDP

Source: World Bank

Container transport logistics (CTL) is "the relevant activities of helping the physical movements of a container box from a point of origin via container ports to a point of destination in a CTLs chain"[6]. Global trade started rigorously developing after the creation of a container – a large box with standardized size for holding a product in storage or shipping.

Containerization led to the radical transformation in transport industry[7]. It caused the creation of new intermodal type of transportation, increased capacities and type of vessels, renovation of port and terminal facilities. So in this transport logistic chain container ports are a foundation of effective in global logistics.

1.1.2 Container ports and terminals functionality and operations

There are two main sizes of containers – TEU or twenty-feet-equivalent-unit and FEU or forty-feet-equivalent-unit. Thus, for the simplicity, it is always considered that 1 FEU is an equivalent of 2 TEU. Containers are appealing mode of transportation for many types of cargos because of

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[6] Min-Ho Ha, Zaili Yang, Jasmine Siu Lee Lam (2019). Port performance in container transport logistics: A multi-stakeholder perspective. Transport Policy, Vol. 73, 25-40

[7] Connecting to compete 2018 : trade logistics in the global economy - the logistics performance index and its indicators (English). Washington, D.C. : World Bank Group. Retrieved June 4, 2020, http://documents.worldbank.org

its ability to scale. For example, the capacity of containership has raised dramatically since the last 70 years – in 1950 ships were able to handle several hundreds of containers, but now the biggest containership, Ultra Large Container Vessel, is able to transport up to 23,500 TEU.

Containerships are generally operated by a certain marine line such as AP Moller Maersk, Mediterranean Shipping Company, CMA CGM, COSCO and many others. Every containership has its maritime route which includes a list of container terminals as stops. Calling for a container port a containership unloads import containers (which is destined to the certain port) and loads exported containers (which are transported to other destinations).

The increasing number of containerships going on the regular basis upon the routes creates the demand on the seaport container ports and terminals, their services and special equipment. It leads to the growing competition among terminals for ships, namely among those terminals who located closely to each other. For example, First container terminal in the port of Saint Petersburg, Bronka container terminal and Container terminal Saint Petersburg, located in Saint Petersburg and nearby, always compete for the same cargo base. Therefore, ports and terminals compete for the patronage of a certain shipping line like Maersk or MSC or may be affiliated with them. The successful factor in this competition is the minimization of transshipment time and low rates for services (loading, unloading). In other words, "a crucial competitive advantage is the rapid turnover of the containers, which corresponds to a reduction of the time in port of the container ships, and of the costs of the transshipment process itself. That is, as a rule of thumb one may refer to the minimization of the time a ship is at the berth as an overall objective with respect to terminal operations"[8].

Therefore, highly efficient container terminals can maximize profit with lower costs for each unit (container). In the short term, the port's margin relies on its abilities to allocate resources in such a way to meet the target of output. To be more precise, it depends from input and output prices and technology used. When a port does not tranship the target number of containers closed to maximum loading, it works inefficiently. Besides, if a port uses not optimal number of inputs even meeting the output target, port still can be considered as inefficient. Apart from that, Bart W. Wiegmans distinguished some several reasons which also explain inefficiency on ports[9]:

- Indivisibilities, or creation of extra capacity which stays unloaded;

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[8] Steenken, D., Voss, S. Stahlbock, R. (2004). Container terminal operation and operations research - A classification and literature review. OR Spectrum. 26., 3-49.

[9] Wiegmans, B. W., Rietveld, P., Pels, E. and Woudenberg, S. V. (2004). Container terminals and utilization of facilities. International Journal of Transport Economics, 31(3), 313–339

- External restrictions (governmental, environmental, etc.), which influence capacity utilization;
- Natural circumstances (high tide, ice conditions) may stop operations in port;
- X-inefficiency refers to the inefficiency of personnel or management.

Therefore, in order to find tough rooms where resources can be used inefficiently, the terminal activities should be examined separately according to each stage of work in port.

Pic.1.1 Typical container terminal system
Source: Monaco, Monicca, Sammarra, 2009

The container handling procedure is highly standardized and requires special equipment. The equipment is always the same, its capacity depends on the size of the port. The basic goal of each port is to transport goods from ship to shore. Depending on different type of activities container terminal can be distinguished on 3 main blocks[10]:

1. Operational area of quayside, where vessels loaded and unloaded;
2. Container yard for stack and storage of containers;
3. Landside area (parking, office buildings, customs facilities, etc.) for loading and unloading trucks or trains transporting containers from hinterland.

Basically, the whole chain of activities looks the following way connecting with the main operation in container terminal - container handling. It starts from the assigning of the containership to the berth on the quayside area. Once the ship was parked, quay cranes started to unload containers. There are 2 main types of cranes for these purpose[11] – ship-mounted cranes (SMC) and ship-to-shore (STS) cranes. The STS cranes are more widely used on modern container terminals. Then container is transported to the quay area or directly on the special vehicle which

[10] Facchini F., Digiesi S., Mossa G. (2020). Optimal dry port configuration for container terminals: A non-linear model for sustainable decision making. International Journal of Production Economics, Vol. 219, 164-178

[11] Böse, Jürgen W. (2011). Handbook of terminal planning. New York: Springer. 456 p.

transports container to the storage yard area. The time of unloading of each container may vary because it depends on how complex the position of container in the vessel is.

In the yard container is stacked until it is loaded again on the other vessel (most likely, feeder or deep sea ship) or moved away to the landside. On the yard container is moved by special stacking equipment like rubber tired gantry cranes (RTG) or rail mounted gantry cranes (RMG) and reach stackers[12].

After that container is transported to the landside by external truck or train which deliver container to the customer. The chain of activities for imported and exported containers requires the same procedures and activities, but in opposite sequence[13].

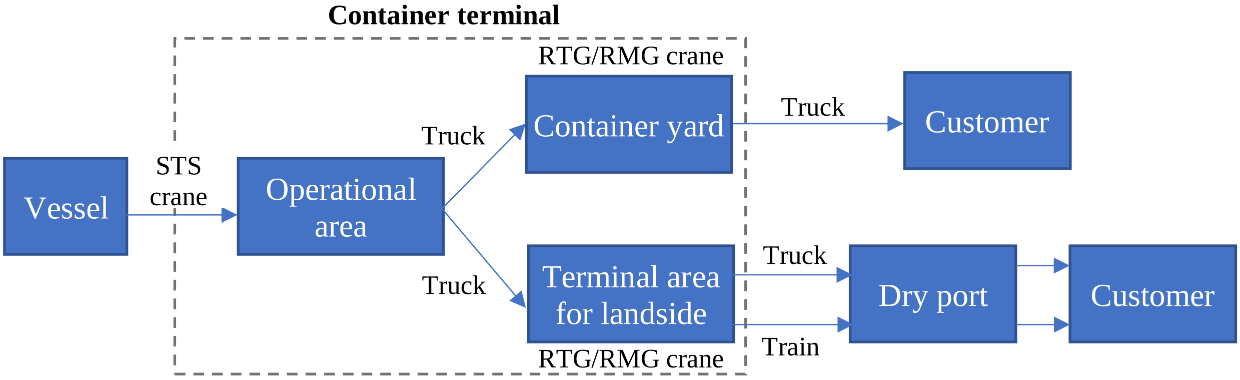

Fig. 2.4 Loading and unloading of containers on the container terminal

Source: F. Facchini, International Journal of Production Economics, 2020

However, it is also should be admitted that overall container terminal capacity should be designed in such a way that does not exceed too much the amount of containers that might be handled in the terminal, because it may lead to spare capacity and economically unfeasible work of the facilities. Moreover, the capacity of the terminal should not be so small that might lead to the disability to serve all containers, therefore some customers may switch their container flow to other competing terminals and this might cause the need to extend the terminal and increase its capacity very soon, which may require massive capital investments.

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[12] Böse, Jürgen W. (2011). Handbook of terminal planning. New York: Springer. 456 p.81

[13] Facchini F., Digiesi S., Mossa G. (2020). Optimal dry port configuration for container terminals: A non-linear model for sustainable decision making. International Journal of Production Economics, Vol. 219, 164-178

Because of the reasons stated above, container terminal efficiency can be seen from the perspective of vessels, customers and inner processes in the terminal[14]:

1. Productivity relates to the number, size and load factors of the vessels called in the terminal, the arrival schedule of vessels and number of containers loaded or unloaded per call;
2. Customer productivity is connected to the customers which provide their containers according to the vessel schedules;
3. Inner processes mean the performance of some internal activities in the terminal such as unloading processes or custom procedures.

In other words, the efficiency of container terminal is focused on actions which act as resources in a terminal and should be minimized or on output which should be maximized with the current amount of resources.

According to this understanding of efficiency, activities such as interaction services in the terminal or port represent the level of efficiency of the terminal. Efficiency of the overall maritime terminals depends on the efficiency of distinct process which takes place in port. For this purpose, several main processes[15] may be distinguished from the fig. 2.4:

1. Berth efficiency;
2. Container handling efficiency;
3. Stack efficiency;
4. Gate efficiency (external truck service).

Therefore, this processes should be taken into account in further study of efficiency of container terminals.

1.1.3 Approaches to capacity measurement

As was pointed in the previous paragraph, for container terminal it is necessary to determine the level of capacity which it could reach because the level of its utilization would be the level of terminal's efficiency. But at the beginning we need to define what should be understood under

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[14] Héctor J. Carlo, Iris F.A. Vis, Kees Jan Roodbergen (2014). Transport operations in container terminals: Literature overview, trends, research directions and classification scheme. European Journal of Operational Research, Vol. 236, Issue 1, 1-13

[15] Wiegmans, B. W., Rietveld, P., Pels, E. and Woudenberg, S. V. (2004). Container terminals and utilization of facilities. International Journal of Transport Economics, 31(3), 313–339

container terminal's capacity. Frankel provided very clear definition of port capacity[16]: "a volume of cargo a port can handle at a given point in time and related to space availability."

Capacity is usually measured by the each element in the operation chain in the port: quay, cranes, stacking area, etc. All of them might have different capacities, but overall the total terminal capacity is defined by the bottleneck capacity among elements of the operation process[17]. For example, if the annual capacity of the cranes and the quay are 500 thousand TEU, but the yard can accept only 200 thousand TEU, the container terminal capacity is 200 thousand TEU.

However, here we should define 2 different types of capacity which port possesses: nominal capacity and throughput handling capacity:

- Nominal capacity – is the maximum throughput which can be handled in the terminal according to nominal engineering parameters of equipment and technical attributes of terminal's infrastructure under ideal conditions without any bottlenecks.
- Throughput handling capacity – the real maximum throughput which can be handled in the terminal accounting for existing practices of serving vessels under realistic operating conditions.

Here we can see that nominal capacity is achieved when all capabilities of equipment and labor resources are exploited. Then it means that nominal capacity always exceeds throughput handling capacity and is hardly achievable in the current operational activities on the terminal since it does not consider the existing practices of serving vessels and unexpected events. These practices are not totally efficient in terms of utilized time and resources because it includes basic realities happening in different activities: human factor, breakage, downtime, unfavorable weather conditions and so on. This unexpected activities are hardly to predict, therefore they reduce nominal capacity to the level of adjusted, actual capacity, which we would call throughput handling capacity.

Therefore, nominal capacity is a non-realistic number which is not corresponded to the real conditions. It means, that it can not be used in any kind of managerial decisions since it gives the wrong understanding of container terminal's abilities. In order to avoid this misconception, the

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[16] Frankel, E.G. (1987) Port Planning and Development. John Wiley and Sons, New York, 795.

[17] Böse, Jürgen W. (2011). Handbook of terminal planning. New York: Springer. 195.

throughput handling capacity should be used because it reflects the real abilities of the container terminal.

Throughput handling capacity should be continuously tracked and corrected in order to avoid overcapacity and inefficient work of the whole terminal, whereas the shortage in capacity leads to the congestions in the terminal and capacity constraints. So the study of throughput handling capacity is required for providing smooth operating process.

However, from the side of the terminal the problem arose how to measure the actual handling capacity. In case of nominal capacity, there are normative acts which state the maximum handled throughput. But the handling capacity is empirical measure which can not be forecasted in the same way. Therefore, in this study the production frontier was made which provides us with the estimations of real handling capacity of the container terminals in Saint Petersburg.

1.2 Performance Analysis: approaches on measuring efficiency

1.2.1 Main approaches on measuring economic performance

One of the objectives of this study is to measure container terminal's performance. It can be assessed through the efficiency evaluation. Therefore, we should analyze the concept of efficiency first.

However, it should be admitted that there are 2 main approaches used for measuring performance of a firm – productivity and efficiency. Although these 2 concepts may seem equivalent and some researches may treat them as synonyms, but basically they are not the same things and should be used as two related notions. The possible reason why these concepts are used as analogues is that the firm's performance becomes better when productivity and efficiency increases. Moreover, there is a visible evidence that the productivity is increasing when the efficiency is increasing too.

Basically there are many various ways to measure productivity, but conceptually it is always understood as the productivity ratio – the ratio between inputs and outputs, where the bigger ratio refers to the higher performance[18]. Regarding efficiency, it is relative indicator which is based on

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[18] González, María Manuela, Lourdes Trujillo (2009). Efficiency Measurement in the Port Industry: A Survey of the Empirical Evidence. Journal of Transport Economics and Policy , 157-192.

the comparison of the similar inputs and outputs with many relative values from firm's competitors[19].

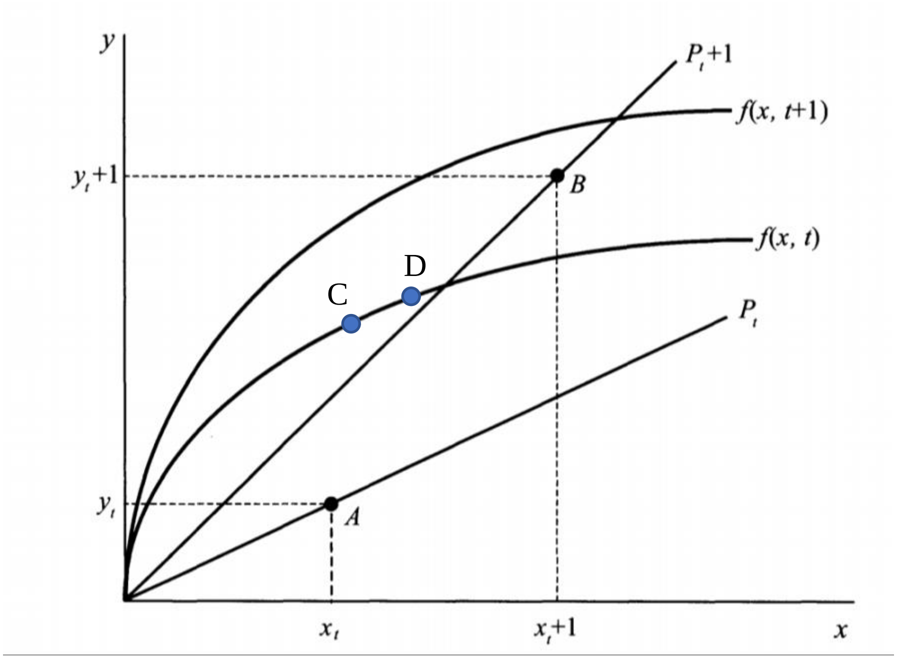

Figure 2.1 Production frontier
Source: adopted from Coelli,2005

This distinction can be demonstrated through production frontier, which is going to represent the level of development of technology in port industry. At the beginning the production frontier is defined by function f(x, t), where x – the amount of input used to get the output. All points on the frontier are efficient ports with efficient resources and products set and inefficient ports will be below the line. Thus, C and D show up as more technically efficient points than A.

The level of productivity can be measured as a slope of a tangent in a certain point which defines the slope of y/x. The steeper the slope the higher the productivity in this point (the higher the ratio of y/x). C and D points defines two technically efficient points but C has a steeper tangent and hence makes it as the point of maximum possible productivity[20]. Getting back to other points alongside the production frontier, for example D, means that the operation at any other point leads to lower productivity.

[19] Coelli Tim, D. S. Prasada Rao, George E. Battese (2005). An introduction to efficiency and productivity analysis, 2nd edition. New York: Springer, 356 p.

[20] Coelli Tim, D. S. Prasada Rao, George E. Battese (2005). An introduction to efficiency and productivity analysis, 2nd edition. New York: Springer, 356 p.

From the results mentioned above it may be concluded that even if a port is technically efficient (its position is somewhere on the production frontier), it may have a room to improve its productivity and to reach the point of maximum possible productivity.

Let's look on a concrete example. The port is in situation A with the current level of productivity P_t with x_t inputs used to obtain y_t output. In the next period t+1 the technical advancement may happen and production frontier may shift to the position f(x, t+1) which leads to the improvement of productivity and now port will operate in the position B. The port becomes more productive with the current technical efficiency in comparison with the former production frontier since the distance between B and frontier t+1 is smaller than the distance between A and frontier t. So the technical advancement as well as technical efficiency both lead to the productivity increase.

1.2.2 Approaches on measuring efficiency

According to Farrell, economic efficiency of the firm consists of the technical efficiency and allocative efficiency[21].Technical efficiency allows company to gain the maximum output from given resources used for final goods production or to gain given output with the minimization of input costs. Allocative efficiency is a selection of set of inputs which can be used for the production of a certain amount of output with the minimum costs.

The main study of this work will we based on the concept of technical efficiency. It could be input-oriented and output-oriented:

- Input-oriented technical efficiency shows the ratio between the minimum required resources and actually used inputs for the production of certain amount of output.
- Output-oriented technical efficiency shows the ratio between the currently gained output and the maximum result that can be obtained from the current amount of resources.

The concept of efficiency may be illustrated through Figure 2. May the companies use two types of resources – x_1 and x_2, for the production of the one y output. Assuming that the return in scale keeps constant, the efficient production function can be defined as an isoquant SS', used for measurement of technical efficiency.

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[21] Farrell, M. J. (1957), The measurement of productive efficiency. Journal of the Royal Statistical Society, Vol. 120, 253-290.

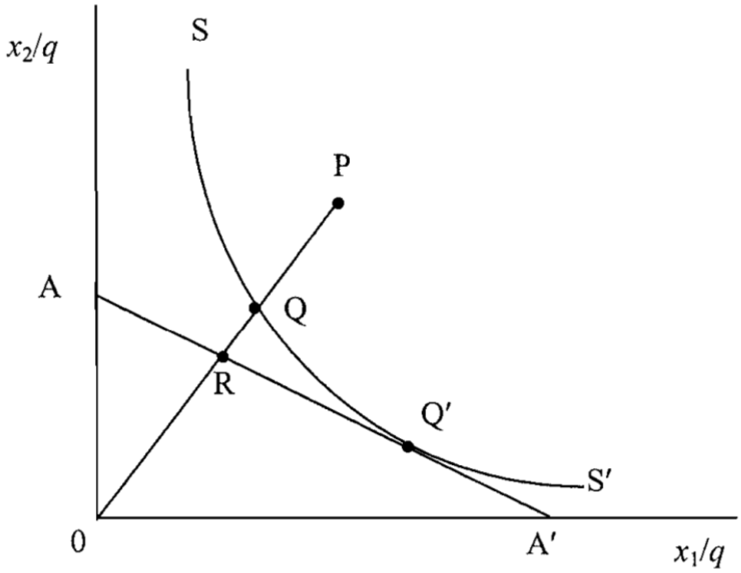

Figure 2.2 Technical and allocative efficiencies
Source: Coelli, 2005

Let us imagine that a company uses x^*_1 and x^*_2 for the production of y* outputs, which is represented by point P. But point P is characterized by technical inefficiency of a firm which may be represented by the distance to SS' or point Q. In other words, it is QP, which shows how all inputs can be decreased with the output amount maintained and the ratio OQ/OP can show by how many present a company can potentially decrease its input. This ratio would have value in a range between 0 and 1 and represents the current degree of technical efficiency of a company.

Every point of isoquant represents different combination of inputs with different prices. Points Q and Q' are equally efficient but they have one big difference in inputs – their prices. Regarding isoquant AA', it is a straight line with constant slope, where all ratios of input's prices are equal. Because points Q' and R lay on the same line AA', they have the same costs of inputs and the allocative efficiency can be defined as OR/OQ. Again, the distance of RQ defines the decrease in production costs which can be done for reaching the allocation effective point R. If the value of ratio equals 1, it means that the firm reaches total allocation efficiency. Otherwise, the ratio shows the progress of a company in achieving efficient production.

As was said in the beginning, total economic efficiency comes from technical efficiency and allocation efficiency. In other words, ratio OQ/OP defines the level of technical efficiency and the ratio OR/OQ - allocation efficiency. Considering that, total economic efficiency is a product of these 2 components and equals OR/OP.

All mentioned above is valid only with the assumption that return on scale is constant. In this case the firm can be considered as scale efficient[22]. But if the return on scale is expected to change or in other words, is between increase and decrease in return on scale[23], a firm may not operate in optimal state, hence, there one more type of efficiency arises – scale efficiency.

Let's have a look on the figure 3. The curve NN' is a production frontier, all firms operating alongside the frontier (A, B, and C) are technically efficient. Although they are all technically efficient, it can be observed that the ratio of input and output (x_i/y_i) will be different in each firm, it can be seen from the different slopes of lines coming from the origin to the each point. The ratio of used input and output values is a productivity by definition, so despite all firms being technically efficient they all possess different productivity, which is caused by the difference in scale.

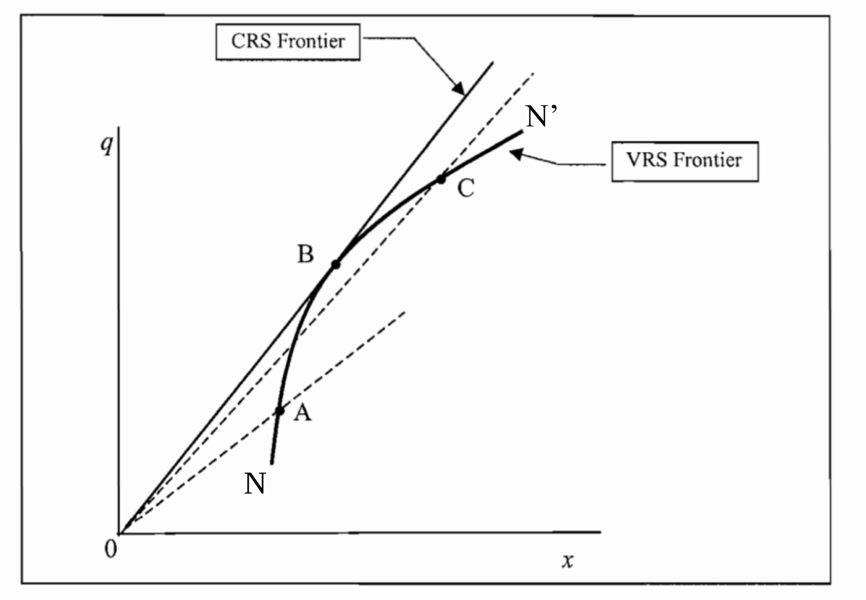

Figure 2.3 The effect of scale

Source: Coelli, 2005

Firm B is the one firm on the frontier which is operating on the technically optimal productive scale[24], because the point B is a tangent to the frontier coming from the origin, which is equal to the point of maximum productivity. Point B cannot become more productive by changing its scale of operation.

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[22] Coelli Tim, D. S. Prasada Rao, George E. Battese (2005). An introduction to efficiency and productivity analysis, 2nd edition. New York: Springer, 356.

[23] Ji, R., Shan, Z. (2019). Research on the Efficiency of Ocean Shipping Enterprises Based on DEA. Journal of Coastal Research, 495-499.

[24] Coelli Tim, D. S. Prasada Rao, George E. Battese (2005). An introduction to efficiency and productivity analysis, 2nd edition. New York: Springer, 356.

Thus, firm A has a position of increasing return on scales and should increment its operations in order to shift in B direction and become more productive. The same is the point C, this firm operates with decreasing return on scale and it could become more productive if it decrement its scale of operations and also move to B direction as well.

Discovering various types of efficiency, it may be concluded that total productivity consists of total efficiency and scale efficiency[25]. In turn of total efficiency, its components are technical efficiency and allocation efficiency. Technical change in efficiency means shift of the frontier up and change in scale efficiency means the movement of a firm alongside the frontier in more optimal position of input-output ratio.

1.2.3 Alternative production frontier models

Before moving to literature review which will examine the best practices on measuring efficiency of container ports and terminals, it is necessary to stop on models which are mainly applied for estimation of frontier in container terminals or ports. Previous researches were based primarily on two models. The first one which uses econometric technics called Stochastic Frontier Analysis (SFA). The second method focusing on linear programming is Data Envelopment Analysis (DEA).

The ground difference between these 2 approaches is that that econometric technic is stochastic and is able to defer noise effects from inefficiency effects, however it is parametric at the same time and misinforms effects of a poor function specification as inefficiencies. Quite the opposite, linear approach is not considered stochastic, therefore it cannot distinguish whether it is noise effects or inefficiency effects, so both of them are regarded as inefficiency. Although, linear programming is not parametric, so this approach is not sensitive to the bad model specification[26].

The key concept of the DEA method is that economic inefficiency of terminals is calculated based on distribution assumptions, so various ports may have different inefficiencies. The main strong point of this method is that there is no a priori justification of the functional form of the data. But because of this, a disadvantage of the method arose - the efficiency measurement can be influenced

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[25] Ji, R., Shan, Z. (2019). Research on the Efficiency of Ocean Shipping Enterprises Based on DEA. Journal of Coastal Research, 495-499.

[26] González, María Manuela, Lourdes Trujillo (2009). Efficiency Measurement in the Port Industry: A Survey of the Empirical Evidence. Journal of Transport Economics and Policy , 157-192.

by some random noise, and because there is no assumptions about the distribution form, therefore statistical tests of hypothesis are not allowed.

The production frontier in DEA is based on the data from the best «producer», which is regarded as efficient state. It is assumed, that all inputs which are used during the production process can fully explain the output. In other words, the random changes in output value are not expected. Thus, the inefficiency of other subjects would be represented through the distance to the production frontier and any deviation from the efficient frontier is stated as inefficiency. Therefore, the efficiency of container terminals would be understood through the comparison of the performance activity of other container terminals.

SFA is a parametric and stochastic approach, which models the production frontier of the firm using regression models for the estimation of inefficiencies. Because of using econometrics concepts, production frontier should be specified. The method also decomposes any deviation from the production frontier into error noise and inefficiency. It should be admitted that the main assumption of the model is that the inefficiency and the error noise are not correlated. Therefore, hypothesis can be statistically checked, however the functional form still requires specification. It leads to the main drawback of this method – when making a model of production frontier, a priori justification of function form in needed.

We took a brief outlook on two the most employed methods in measuring performance of marine terminals. Summing up, none of these two methods dominates each other, both of them have strong and weak sides. For many authors the choice between them is the matter of personal beliefs, competences of researches and data availability. Therefore, the usage of one of the methods depends on the individual aims of study and concrete goals which should be met. What regards studies of measuring the performance of container terminals, researches have not got consensus on which method better reflects the port performance, which will be proved in the literature review.

1.3 Summary of Chapter 1

Overall, during the process of trade development, the container was discovered. It turned out that a lot of different cargo may be containerized, therefore there is a global tendency of container transportation of goods. Moreover, container transportation grows annually with CAGR 6,5%. Because of that the need in container terminals is increasing since they have the strategic role in the maritime logistic chain. Container ports and terminals have the same operational activities on quay, yard and landside, therefore their performance can be comparable. However, the utilization of container terminal handling capacity should be used as an indicator of the port performance, since it reflects the actual capabilities of container terminals to serve throughput.

CHAPTER 2. THEORETICAL BACKGROUND

2.1 Analysis of the previous studies about efficiency measurement in ports

2.1.1 Study scope in existing literature

Literature review is dedicated to the analysis of container terminals' performance. Economic efficiency is a fundamental concept in this field and is differently defined in various textbooks. The concept mainly concerns the economic use of resources (resources) for production. Given the limited and finite nature of the resources available at the disposal of each production process, the importance of studying efficiency is evident.

At the first stage of literature review, the selection of articles was made from the most authoritative databases —EBSCO, JSTOR, Wiley Online Library and Elsevier. Next step was the deep analysis of earlier researchers of the measuring port efficiency using various mathematical methods.

The search for articles was carried out by the search query "operational efficiency", "efficiency of terminals", "efficiency measurement" and was carried out in the following sections: title, abstract and keywords. The time period of articles was restricted by 2014-2020 years. In the selection process, repetitive articles were excluded, as well as articles that do not correspond to the general theme of the study. After all, 15 articles were suggested for further analysis (Table 3.1). Only articles which has port's efficiency as a main field of research were taken.

The majority of selected articles explore the phenomenon of economic performance of ports or container terminals using data envelopment analysis or stochastic frontier analysis depending on the data availability. It is clear that the objective of ports may be different from the objectives of terminals, especially those which are focused on container throughput. However, if the specification of port and terminal models is investigated, it is found out that the inputs and outputs are frequently the same, which mitigates the distinction between ports and terminals. For example, Monteiro explored the port efficiency using port throughput in tones as a output. At the same time, Zarbi used the volume of containerized goods expressed in TEUs as an output. Overall, these outputs measure the same result of the activities conducted in ports and terminals because in the first and the second case it is a throughput but in different measurement system. But this difference can be easily overcome by transferring TEU in tones using the average coefficient of container loading.

The same regards inputs, Monteiro[27] used port area, number of personnel (all types of workers), number of cranes (mobile, gantry, etc.), number of other equipment (reefers, stackers, locomotives, etc.), number of berths as inputs. Kutin[28], who explored container terminals, used max depth at berth, size of the container yard, length of the quays, number of quays cranes, RTG cranes, yard cranes (RMG, SC, RTG), forklifts, trucks. Despite of being a port or terminal, researchers considered the same inputs which included different port areas, cranes and equipment. Cranes and equipment which is stated earlier are the same for container and non-container ports. So, the equality in outputs and inputs of ports and container terminals allows us to consider these both types of researches.

Researchers use different geographical scope in their analysis. For ports being an infrastructure asset, its geographical location is one of the key characteristics, therefore the selection of ports is also important. Within the selection of articles for literature review there are three main groups of studies distinguished by their geographical scope: national, regional, worldwide.

For example, Bo Lu examines the performance of the top 20 container terminals in the world. His study aims to compare efficiency of the leading terminals in terms of their throughput in the global context and distinguish the ranking of these ports. Such study may be used as a benchmark of efficiently-working ports.

Regional-oriented studies such as Wang, Jiang, Shan[29] observed 3 main ports in China, Singapore and South Korea. Kutin, Nguyen, Vallee[30] observed 50 container terminals in the ASEAN region and Wiegmans[31] studied 26 leading container terminals in Europe. Study on the efficiency of the region-specific base gives researchers an understanding of performance of the ports from one certain economic region, for example, ASEAN countries or Europe region. Such regional analysis shows the difference in efficiency of the terminals which compete on the same market and situated in the various countries.

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[27] Monteiro, J. (2010). Measuring Productivity and Efficiency of Major Ports of India. Economic and Political Weekly, 45(26/27), 325-331

[28] Kutin, Nguyen, Vallee (2017). Relative efficiencies of ASEAN Container ports based on Data Envelopment Analysis. The Asian Journal of Shipping and Logistics,Vol. 33, Issue 2, 67-77

[29] Wang, J., Jiang, X., Shan, C. (2019). International Reference for Efficiency of Shanghai Transportation Service Trade in the Construction of a Free Trade Port. Journal of Coastal Research, 26-29.

[30] Kutin, Nguyen, Vallee (2017). Relative efficiencies of ASEAN Container ports based on Data Envelopment Analysis. The Asian Journal of Shipping and Logistics,Vol. 33, Issue 2, 67-77

[31] Wiegmans Bart W., Rietveld Piet, Pels Eric, van Woudenberg Stefan, Container terminals and utilization of facilities (2004), International Journal of Transport Economics, Vol. 31, No. 3, 313-339

Lastly, the biggest group of studies was devoted to the efficiency measurement among national ports which situated in one country. For example, Beatriz López-Bermúdez studied 20 container terminals in Brazil[32] and 13 container terminals in Argentina[33]. Zarbi, Shin and Shin[34] evaluated 10 container ports in Iran, Akinyemi[35] – 8 ports in Nigeria, Monteiro[36] – 12 major ports in India and Halkos, Tzeremes[37] – leading Greek ports. This country-centric type of research is mainly used to evaluate the port's performance in order to distinguish the drivers of the efficiency and productivity. By doing this, a company can take actions which may lead to the increase of efficiency or productivity of ports and increase its competitive advantage. Moreover, some researchers, for example, Monteiro and Zarbi, Shin, Shin, studied the influence on the efficiency of container terminals or ports due to some events such as sanctions or privatization.

Regarding the dataset which is used for empirical part of the study, all selected articles used panel data as a main structure of data. Panel data is a structure of observations which represent different characteristics during some period of time. It means that each observation contains a set of various characteristics which is changing in dynamics. Using panel data may assure the accurate in the measurement of port performance over the period of time. For example, in the articles researchers collected some specific characteristics for each port such as throughput, number of cranes and the length of the quayside changing in the period of 5-10 years. This cross-sectional dataset helped them to observe the change in the efficiency of ports and distinguish factors which influence the change in efficiency and explore the overall market overview.

The choice of the methods mostly depends on the objective of the study. However, the objective of researches may vary according to time period, economic conditions, development of the regions and many more other aspects, but in general, all studies can be connected with the one goal – to evaluate the port/terminal performance in terms of its efficiency or productivity and distinguish

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[32] Beatriz López-Bermúdez, María Jesús Freire-Seoane, Fernando González-Laxe (2019), Efficiency and productivity of container terminals in Brazilian ports (2008–2017), Utilities Policy, Vol. 56, 82-91

[33] Beatriz López-Bermúdez, María Jesús Freire-Seoane, Diego José Nieves-Martínez (2019), Port efficiency in Argentina from 2012 to 2017: An ally for sustained economic growth, Utilities Policy,Vol. 61

[34] Zarbi, S., Sang-Hoon Shin, Yong-John Shin (2019). An Analysis by Window DEA on the Influence of International Sanction to the Efficiency of Iranian Container Ports, The Asian Journal of Shipping and Logistics,Vol.35, Issue 4, 163-171

[35] Akinyemi Y.C. (2017), Port reform in Nigeria: efficiency gains and challenges. GeoJournal, Vol. 81, No.5, 681-697

[36] Monteiro, J. (2010). Measuring Productivity and Efficiency of Major Ports of India. Economic and Political Weekly, 45(26/27), 325-331

[37] George E. Halkos, Nickolaos G. Tzeremes. (2015). Measuring Seaports' Productivity: A Malmquist Productivity Index Decomposition Approach. Journal of Transport Economics and Policy, 49(2), 355-376.

the factors which influence port efficiency. To be more specific, among selected articles there are 2 main groups of objectives:

SFA method has different objectives for its application among selected articles, but the general goal is to conduct efficiency analysis with the influence of a certain event, which is basically the first group stated earlier. In the literature reviewed these events were connected with privatization, sanctions, decentralization, etc. For example, Akinyemi[38] studied the impact of restructuring and privatization on the efficiency of Nigerian ports: the reform of port sector was accepted in Nigeria and according to its privatization program was started. The main aim of this reform was to increase the efficiency of ports' operation and foster the development of overall port industry in the country. Panel data of 8 ports was used to explore the difference of efficiency before and after privatization from 2006 to 2010. For this purpose SFA method was applied. The result of the study indicated that the efficiency of ports' operations increased from 59% to 75% and there were improvement in cargo throughput, number of vessels and berth occupancy.

DEA method allows researchers to make multiple input-output cases. The purpose of usage this method is the accessibility of data which may be collected in the research purpose. It should be also admitted that the data should be homogeneous so researchers consider ports which are similar in terms of some characteristics, for example, terminal area or the number of equipment, which makes ports comparable. For example, Wang, Jiang, Shan [39]studied the ways of efficiency increase for Shanghai free trade port due to the opening of The Lingang New Area of free trade port. Therefore, the efficiency of port operations is one of the main competitive characteristics among other international ports located in the same Asian region such as Busan or Singapore. For this purpose researchers took total transportation, total seaborne transportation, and cargo throughput as output indicators. As for inputs, they were weighted average tariff rate, market access, port basic services, port facility, and port communication level. This study is an example of multiple input-output model. The final result of the study showed that there is a gap in different type of efficiencies between Shanghai port and top-leading international free ports of Busan and Singapore. That is why their examples should be taken like a royal model for the future development plans of Shanghai free port.

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[38] Akinyemi Y.C. (2017), Port reform in Nigeria: efficiency gains and challenges. GeoJournal, Vol. 81, No.5, 681-697

[39] Wang, J., Jiang, X., Shan, C. (2019). International Reference for Efficiency of Shanghai Transportation Service Trade in the Construction of a Free Trade Port. Journal of Coastal Research, 26-29.

Another example of multiple input-output model is considered in the work of Monteiro[40] who would like to compare the efficiency level of main ports of India. These ports are suffering of several problems such as lack of draft and connectivity, excessive bureaucracy and low efficiency and productivity overall due to the overutilization of current capacities. For the purpose of exploring the change in port efficiency Monteiro used multiple input-output model, where the volume of cargo traffic in million tones and number of vessels handled served as outputs, inputs of the model were connected with quality of the service, quantity of facilities and others. As a result, during the analysis it was discovered that the efficiency indexes would hardly improve in the future. Therefore, the conclusion was made that the major ports of India are overexploited and further renovation, modernization and mechanization is needed.

It also should be added that researchers used different configuration of DEA model in their studies. For example, Kutin, Nguyen and Vallee applied DEA-CCR and DEA-BCC models investigating the efficiency of container port using return to scale approach, where CCS – constant return to scale or certain increase in inputs leads to the same increase in outputs; BCC – variable return to scale or certain increase in inputs leads to the disproportional increase or decrease in outputs [41]. Combining these 2 approaches in studies, researches made sensitivity analysis and found out how different outputs impact on the port performance and which inputs and outputs are more significant for the model.

DEA-Super-efficiency configuration used by Bo Lu[42] is used for ranking efficient ports, which have the first place in the initial ranking when applying simple DEA model[43]. DEA Window model applied by Zarbi, Shin and Shin estimated the change in efficiency of Iranian container terminals over a specific period of time when the sanctions were valid.

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[40] Monteiro, J. (2010). Measuring Productivity and Efficiency of Major Ports of India. Economic and Political Weekly, 45(26/27), 325-331

[41] Saeedi, H., Behdani,B., Wiegmans, B., Zuidwijk, R. (2019). Assessing the technical efficiency of intermodal freight transport chains using a modified network DEA approach. Transportation Research Part E: Logistics and Transportation Review, Vol. 126, 66-86.

[42] Lu, B., Park, N., & Huo, Y. (2015). The Evaluation of Operational Efficiency of the World's Leading Container Seaports. Journal of Coastal Research, 248-254.

[43] Noura A.A., Hosseinzadeh Lotfi F., Jahanshahloo G.R., Fanati Rashidi S (2011), Super-efficiency in DEA by effectiveness of each unit in society, Applied Mathematics Letters, Vol. 24, Issue 5,623-626

Table 2.1 Overview of existing port efficiency studies by the application of different methods

Research	Description of data	Goal	Inputs	Method	Function form	Output	Type of efficiency measured
Beatriz López-Bermúdez Efficiency and productivity of container terminals in Brazilian ports (2019)	Panel data of 20 container ports in Brazil between 2008-2017, 200 observations	To analyze the efficiency and productivity of terminals containerized goods in Brazil	1. Frequency of calls, 2. Cranes for the operation of handling the contained goods, 3. Draft, 4. Location, 5. Port infrastructure quality index 6. Privatization	SFA	Translog	The volume of containerized goods expressed in TEUs	Technical efficiency
Beatriz López-Bermúdez Port efficiency in Argentina from 2012 to 2017: An ally for sustained economic growth (2019)	Panel data of 13 container terminals in Argentina between 2012-2017 78 observations	To analyze the efficiency and productivity of terminals containerized goods in Argentina	1. Frequency of calls, 2. Number of gantry and mobile cranes 3. Belonging to the city of Buenos Aires 4. Fluvial or oceanic location	SFA	Translog	The volume of containerized goods expressed in TEUs	Technical efficiency
Zarbi, Shin, Shin An analysis by Window DEA on the influence on international sanction to the efficiency of Iranian Container Ports (2019)	Panel data of 10 container ports in Iran between 2008-2017	To evaluate the Iranian ports' performance and the influence of sanctions on the Iranian ports' business, shipping and container cargo volume during the sanction period in order to better prepare to countermeasures	1. Length of the quays 2. Number of quays 3. Number of gantry cranes 4. Size of the container yard	DEA Windows	-	The volume of containerized goods expressed in TEUs	Technical efficiency

Wang, Jiang, Shan International Reference for Efficiency of Shanghai Transportation Service Trade in the Construction of a Free Trade Port (2019)	Panel data of 3 ports in China, Singapore and South Korea between 2006-2011,	To makes a horizontal comparison in efficiency evaluation among Shanghai Port, Singapore Port, and Busan Port to achieve the strategic goal of the free trade port	1. Weighted average tariff rate, 2. Market access, 3. Port basic services, 4. Port facilities, 5. Port communication level	DEA	-	1.Total transportation 2.Total seaborne transportation 3.Cargo throughput in tones	Technical efficiency, Scale efficiency
Kutin, Nguyen, Vallee Relative efficiencies of ASEAN Container ports based on Data Envelopment Analysis (2017)	Panel data of 50 container terminals in ASEAN between 2012-2017 141 observations	To analyze the most efficient ports according to their type (inland or sea) and their container yard equipment	1. Max depth at berth 2. Size of the container yard 3. Length of the quays 4. Number of quays cranes 5. Number of RTG cranes 6. Number of yard cranes (RMG, SC, RTG) 7. Number of FTs 8. Number of trucks	DEA-CCR, DEA-BCC	-	The annual volume of containerized goods expressed in TEUs	Technical efficiency
Akinyemi Port reform in Nigeria: efficiency gains and challenges (2017)	Panel data of 8 container ports in Nigeria between 2000-2005 and 2006-2010 108 observations	To estimate efficiency changes in the port due to the privatization	1. Total terminal area 2. Total berth length 3. Waiting time	SFA	Translog, Cobb-Douglas	The volume of containerized goods expressed in TEUs	Technical efficiency
Monteiro Measuring Productivity and	Panel data of 12 major ports in India between 2001-2008	1. To identify indicators and compare the	1. Port area 2. Number of personnel (all types of workers)	DEA	Malmquist productivity index	1.The volume of cargo traffic in million tones	Total factor productivity, Technical efficiency

Efficiency of Major Ports of India (2010)		performance of major ports of India 2. To measure the levels of total factor productivity of major ports	3. Number of cranes (mobile, gantry, etc.) 4. Number of other equipment (reefers, stackers, locomotives, etc.) 5. Number of berths			2.Number of vessels handled	
Bo Lu The Evaluation of Operational Efficiency of the World's Leading Container Seaports (2015)	Panel data of 20 leading container ports in the world between 2001-2008	1. To identify efficient container ports and rank their sequence 2. Find out the reasons of inefficiency of some ports	1. Yard area per berth 2. Number of quay cranes, yard cranes 3. Number of yard tractor per berth 4. Berth length	DEA-CCR, DEA-BCC, DEA-Super-efficiency	-	The volume of containerized goods expressed in TEUs	Total efficiency, Technical efficiency
Wiegmans Container terminals and utilization of facilities (2004)	Panel data of 26 leading container terminals in Europe in 1999	To determine production frontiers and efficiency coefficients for container terminals	1. Size of the terminal area 2. Number of cranes 3. Length if berth	DEA, SFA	Cobb-Douglas	The volume of containerized goods expressed in TEUs	Technical efficiency
Halkos, Tzeremes Measuring Seaports' Productivity: A Malmquist Productivity Index Decomposition Approach (2015)	Panel data of Greek ports between 2006-2010	To detect how the size of the examined seaports has affected their productivity level	1. Total assets 2. Number of personnel	DEA	Malmquist productivity index	1.Number of passengers travelled 2.Tones of merchandise	Technical efficiency

2.1.2 Analysis of model specification in the existing literature

Previously we discussed the general objectives of selected studies and made the general overview of the data and methods used in empirical research purposes. Now the aim of this paragraph is to analyze the variable specifications of that studies.

Overall, the main port activities were discovered and described in the 1.1 chapter. Ideally, the majority of them should be taken into account in port performance analysis because they directly relate to the efficiency and productivity concepts. But in empirical researches the issue what variable include to the model highly depends on the availability and the quality of the data. This limitation seriously influence the range of possible activities or other characteristics which may be explored. DEA bases its models on multiple input-output model, whereas SFA uses only single output model.

The problem of data limitation influence studies to focus on the analysis of specific type of efficiency. From the paragraph 1.3 we have already known that there are different levels of efficiency: technical efficiency, allocative efficiency, scale efficiency and total economic efficiency. However, in the majority of articles researches investigate technical efficiency. Partially it may be explained by access to technical characteristic and facilities of ports and terminals. However, some authors such as Wang, Jiang and Shan explored scale efficiency[44]. Monteiro measured total factor productivity using Malmquist index[45]. Bo Lu studied total efficiency[46].

Starting with SFA method, it should be reminded that it is single output model due to the technical aspects of this method. Therefore, in the majority of the studies which are focused on the analysis of performance of container terminal or container port, the volume of containerized goods expressed in TEUs was chosen as main output factor (Beatriz López-Bermúdez[47], Akinyemi[48],

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[44] Lu, B., Park, N., & Huo, Y. (2015). The Evaluation of Operational Efficiency of the World's Leading Container Seaports. Journal of Coastal Research, 248-254

[45] Monteiro, J. (2010). Measuring Productivity and Efficiency of Major Ports of India. Economic and Political Weekly, 45(26/27), 325-331

[46] Lu, B., Park, N., & Huo, Y. (2015). The Evaluation of Operational Efficiency of the World's Leading Container Seaports. Journal of Coastal Research, 248-254

[47] Beatriz López-Bermúdez, María Jesús Freire-Seoane, Fernando González-Laxe (2019), Efficiency and productivity of container terminals in Brazilian ports (2008–2017), Utilities Policy, Vol. 56, 82-91

[48] Akinyemi Y.C. (2017), Port reform in Nigeria: efficiency gains and challenges. GeoJournal, Vol. 81, No.5, 681-697

Wiegmans[49]). This output absolutely clear shows the result of the port activities. However, if it is a multiple cargo port or terminal which can handle not only containers but dry or liquid balk, general cargo or even passenger traffic like it is in the study of Halkos and Tzeremes[50], then a single output variable as the throughput in TEU is not applicable. Therefore, some researchers take the volume of throughput expressed in tones[51]. So because of the need to clearly express the output of the port, the DEA model can be used, which allows to consider different type of cargo as several output factors. For example, Monteiro in his research considered the volume of cargo traffic in million tones and number of vessels handled. Halkos and Tzeremes considered number of passengers travelled and tones of merchandise. Wang, Jiang and Shan examined total transportation, total seaborne transportation and cargo throughput in tones. But despite considering multiple output models, TEU is still prior output which is the most representative variable for container port or terminal.

Table 2.2 Grouped inputs in existing literature

Infrastructure characteristics	**Equipment**	**Labor**	**Services**	**Other qualitative characteristics**
1. Max depth at berth 2. Size of the container yard 3. Length of the quays 4. Draft 5. Total terminal area 6. Total berth length 7. Number of berths 8. Yard area per berth	1. Number of quays cranes 2. Number of RTG cranes 3. Number of yard cranes (RMG, SC, RTG) 4. Number of FTs 5. Number of trucks 6. Number of cranes (mobile, gantry, etc.) 7. Number of other equipment (reefers, stackers, locomotives, etc.) 8. Number of yard tractor per berth 9. Total assets	1. Number of personnel (all types of workers)	1.Frequency of calls 2.Weighted average tariff rate, 3.Port basic services	1. Location, 2. Port infrastructure quality index 3. Privatization 4. Market access

Regarding inputs, there is no so strict regulation what variable to choose because in general all inputs are connected with the final output of the port activity and influence the port performance. Moreover, the selected set of inputs does not depend from the method which was used in the study

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[49] Bart W. Wiegmans, Piet Rietveld, Eric Pels, Stefan van Woudenberg (2004), Container terminals and utilisation of facilities. International Journal of Transport Economics, Vol. 31, No. 3, 313-339

[50] Bart W. Wiegmans, Piet Rietveld, Eric Pels, Stefan van Woudenberg (2004), Container terminals and utilisation of facilities. International Journal of Transport Economics, Vol. 31, No. 3, 313-339

[51] Wang, J., Jiang, X., Shan, C. (2019). International Reference for Efficiency of Shanghai Transportation Service Trade in the Construction of a Free Trade Port. Journal of Coastal Research, 26-29.

– DEA and SFA models have the same input configuration. Among all selected studies, it can be distinguished 4 main groups of input specification: technical characteristics, equipment, labor, services, qualitative characteristics (table 2.2). The majority of analyzed articles focuses on technical characteristics and port equipment as main groups of input since they directly influence the port performance.

2.1.3 Function form

In paragraph 2.4 we stated that SFA is a parametric method, so production frontier should be specified while DEA does not need the same specification. In the explored literature there are two main type of functions which lay in the specification of the port performance SFA models – Cobb-Douglas production function and Translog cost function. The choice of the right function is very important because it reflects the relation between inputs and production technique. That is why appropriate assumptions should be made, which depends on the researcher's perception of the goal of a port – to maximize profit or minimize costs. The production function influences the shape of production frontier and the accuracy of the study.

Coming from its name, production function known as Cobb-Douglas establishes the relation between the output of the production process and inputs which is used in the process of production. In other words, it reflects the maximum amount of output which may be gained from the given set of resources, which are called production factors – labor, capital, technical progress, etc[52]. The most commonly used function includes labor and capital, but the number of production factors may be extended depending on the study objectives and availability of the data:

$$\ln y = \beta_0 + \sum_{n=1}^{N} \beta_n \ln x_n$$

Where:

- $\ln y$ – natural logarithm of the output factor;
- β_0 – constant;
- β_n – elasticity related to the production factor x_n;

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[52] Labini P.S. (1995). Why the interpretation of the Cobb-Douglas production function must be radically changed. Structural Change and Economic Dynamics, Vol. 6, Issue 4, 485-504.

- $\ln x_n$ - natural logarithm of production factor.

The function is sensitive to elasticity and can show increasing, decreasing and constant return on scale when β_n>1, <1, =1.

A transcendental logarithmic function or translog is commonly used for the analysis of cost structures in different industries:

$$ln\, y \;=\; \beta_0 \;+\; \sum_{n=1}^{N} \beta_n ln\, x_n \;\; + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{M} \beta_{nm} ln\, x_n ln\, x_m$$

Where:

- $\ln y$ – natural logarithm of the output factor;
- β_0 – constant;
- β_i – elasticity related to the production factor x_i;
- $\ln x_n$ / $\ln x_m$ - natural logarithm of production factor.

The objective of Translog function is to show the cost which is needed to produce the certain amount of output.

It is flexible generalization of Cobb-Douglas function, but in Cobb-Douglas function it is assumed that the technological effect should be constant over period of time, but in Translog there is a possibility to apply change of it[53]. Due to the high relativity of these 2 functions it becomes possible to compare results of their studies.

2.2 Summary of Chapter 2

In this chapter the literature review was conducted. For this purpose 15 articles focusing on measurement of technical efficiency were analyzed. The selected publications were thoroughly examined on their goal of the study, methodology, variables, quantitative models applied and model specifications. Here the evidence of research gap is provided - no study has been found that identified the infrastructure variables which influence the handling capacity of the terminal.

From the literature review we defined the groups of variables used in the best examples of efficiency study. They will be taken into account for the model specification in our further research.

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[53] Coelli Tim, D. S. Prasada Rao, George E. Battese (2005). An introduction to efficiency and productivity analysis, 2nd edition. New York: Springer, 356 p.

CHAPTER 3. METHODOLOGY OF THE RESEARCH

In the previous chapter we examined different approaches which are applied to the measurement of container port performance. We reviewed various methods for model creation, model specification in terms of chosen input and output factors and received results in the most up-to-date studies. In this chapter we are going to design the methodology for the examination and benchmark of container terminal performance in Russia and technical efficiency study. The key methods which are going to be applied in this work is quantitative methods including regression analysis and production frontier analysis. These methods were successfully applied in the reviewed literature. Using this approach it is possible to make a design of analytical models for measuring an impact of the infrastructural variables on the container terminals handling capacity. Therefore, in this chapter we are going to develop the research methodology and dig deeper into the specification of variables which would describe the infrastructural characteristics of container ports and terminals.

3.1 Research design

The empirical part of the study is conducted in the several consequential parts. Such design aims to reach the main goal of this work – to make a design and application of analytical models for measuring an impact of the infrastructural variables on the container terminals handling capacity. However, in order to reach this target the list of objectives which were set in the beginning of the work should be met. For this reason, the empirical part of this thesis was divided into 4 main stages:

- ***Stage 1. Operationalization of the container terminal handling capacity concept and identification of container terminal infrastructure variables influencing handling capacity.***

  On the chapter 1.1.3 we defined 2 types of capacity measured in container terminals. There we also operationalized the throughput handling capacity and its difference from nominal capacity. Besides, we highlighted the importance of throughput handling capacity consideration in this study.

Then we should identify the set of variables which should reflect the characteristics of container terminal infrastructure. As it may be seen on 1.1.2 chapter, we had an overview of main container terminals' activities and operations where the infrastructure tools and used. The aim of that part was to give the general understanding of what infrastructure peculiarities a terminal has. In addition to that, the set of variables would be also considered according to the best practices discovered in the literature review analysis and interviews with container market experts.

Here we also need to collect sound database for further analysis. For the observants we take the terminals focusing mainly on the container cargo serving. As we study the impact of infrastructure characteristics, it makes sense to collect the data in the particular time period in order to check the dynamics of their influence on the output variable. In order to provide up-to-date and reliable data the official governmental and terminal sources of information are chosen.

- ***Stage 2. Causal modeling of relationship between the container terminal throughput and its infrastructure variables.***

After the identification of infrastructure variables and collection of the appropriate data, the cause and effect analysis should be conducted. For this purpose the casual modeling of relationship between the container terminals throughput and their infrastructure characteristics would be made. The casual modeling would use the regression analysis as a quantitative method. It should be also admitted that for the model specification we use the Cobb-Douglas function because this production function shows the technological relationship between the throughput and all infrastructure inputs.

At the beginning it is planned to use all infrastructure variables as inputs in the model because they are expected to have the impact on throughput of container terminals. Then all necessary correction can be made.

The result of this stage is planned to obtain the model with a good fit which shows the causality between throughput and infrastructure variables. Having the list of significant variables we know which characteristics also influence the terminal handling capacity. It helps us to move on to the next stage dedicated to the production frontier modeling.

- ***Stage 3. Construction of the alternative production frontier models. Comparative analysis of technical efficiency of the container terminals handling capacity.***

  After the identification of variables influencing the container terminals' throughput and as a consequence, the handling capacity, on the collected database, production frontier analysis can be made. For this purpose the stochastic frontier analysis was chosen. The thorough description of this method will be further in the text.

  This parametric method is able to project the production frontier of observed container terminals. In addition to that, the production frontier makes the projections on the empirical estimations of container terminals' handling capacity and their level of technical efficiency. On the basis of these projections made it is possible to forecast the empirical handling capacity in accordance to the infrastructure characteristics.

  Having these estimates we can compare the levels of technical efficiency among chosen container terminals and make conclusions on their performance.

- ***Stage 4. Investigation of relationship between technical efficiency of terminal handling capacity and its infrastructure characteristics.***

  Obtaining the estimation of technical efficiency and throughput handling capacity, we can investigate the relationship between technical efficiency of terminal handling capacity and its infrastructure characteristics. Again, by using regression analysis we find out the functional relationship between infrastructure variables and handling capacity of the container terminal.

  As a result of the empirical part, we come to the model with Cobb-Douglas functional form for the forecast of the handling capacity of container terminals. This model can be used as a decision-support tool for the terminal's authorities.

3.2 Stochastic frontier analysis framework

After the publication of pioneer work of Farrell[54], several approaches for the efficiency study emerged. However, they can be divided on the two big groups:

1. Parametric Stochastic Frontier Analysis, initially proposed by Aigner[55] and Meeusen and Van den Broeck[56];
2. Non-parametric Data-Envelopment Analysis, firstly developed by Charnes[57].

The choice between these 2 methods is controversial and highly depends on the objectives of study. Moreover, the data and its quality also influence the choice of the method. Therefore, there is no wrong or right method to apply, because they lead us to the different results. However, there are some basic aspects of the methods which we should take into account. For example, DEA as a non-parametric method is not based on the functional for on the current technology. On the same time, it helps to avoid the misspecification problem. But DEA is a deterministic model and does not take into account any stochastic component which explains the deviation from the production frontier because of inefficiency. Therefore, SFA is more accurate than DEA.

This study adopts Stochastic Frontier Analysis since it considers the existence of technical inefficiency and may distinguish the influence of random shocks to output variables. These make the model more reliable.

Here we will investigate the mathematical background of Stochastic Frontier Analysis. Corresponding to microeconomics theory, Farrell[58] explained the output factor y_i with the production frontier $f(x_i;\beta)$ as follows:

$$y_i = a_i f(x_i;\beta)$$, where

- y_i – the output of each firm;
- x_i – production factors which influence the output;

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[54] Farrell, M. J. (1957), The measurement of productive efficiency, Journal of the Royal Statistical Society, Vol. 120, pp.253-290.

[55] Aigner D., Lovell C., Schmidt P., Formation and Estimation of Stochastic Frontier Production Function Models. Journal of Econometrics, 1977, 6. 21-37.

[56] Meeusen W., van den Broeck, J., (1977), Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error, International Economic Review, 18, issue 2, p. 435-44.

[57] Charnes, A., Cooper, W.W., Rhodes, E.,(1978). Measuring the efficiency of decision making units. European Journal of Operational Research. 2, 429–444.

[58] Farrell, M. J. (1957), The measurement of productive efficiency, Journal of the Royal Statistical Society, Vol. 120, pp.253-290.

- β – coefficients of x_i;
- a_i – the level of efficiency, which lays in the interval $0 < a_i \leq 1$.

The coefficient of efficiency a_i is applied in the function since in the real life each company is not able work permanently maximizing their efficiency in the allocation of resources and producing maximum of output.

In 1977 Aigner, Lovell, Shmidt[59] and Meeusen, van den Broeck[60] originally developed and independently announced their studies about stochastic production frontier model, which is output oriented. They proposed the basic framework for SFA in a regression specification which requires natural logarithmic transformation in the following way:

$$lny_i = lny_i^{max} - u_i\,,\ u_i\ \geq 0,$$

$$lny_i{}^{max} = lnf(x_i;\beta) + v_i - u_i, \text{ where}$$

- v_i – zero-mean random errors representing stochastic noise;
- $u_i = -\ ln\ a_i \geq 1$ –non-negative variables representing technical inefficiencies;
- $lny_i{}^{max} = lnf(x_i;\beta) + v_i - u_i$ represents the stochastic production frontier function. The unit gets the maximum possible level of output y with the given amount of inputs x_i. Such frontier can be considered stochastic because v_i is present.

Here we can observe the main difference from the standard production frontier which was described earlier – the presence of two error terms in the stochastic model. It means, that the production process may be disturbed by two "economically distinguishable random disturbances"[61] with different characteristics.

Sometimes it is more convenient to represent the model in the following way:

$$lny_i = lnf(x_i;\beta) + \epsilon_i,$$

$$\epsilon_i = v_i - u_i, \text{ where}$$

ϵ_i is the error term which is usually called composed error term.

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[59] Aigner D., Lovell C., Schmidt P. (1977), Formation and Estimation of Stochastic Frontier Production Function Models. Journal of Econometrics, 21-37.

[60] Meeusen W., van den Broeck, J., (1977). Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error. International Economic Review, 435-44.

[61] Aigner D., Lovell C., Schmidt P. (1977), Formation and Estimation of Stochastic Frontier Production Function Models. Journal of Econometrics, 21-37.

The first component $v_i \sim N(0, \sigma_v^2)$ is aimed to capture the effect of statistical noise and is assumed to be independently and equally distributed. In other words, random disturbance v_i is out of firm's control. It could be some externalities such as luck, sanctions, pandemic, etc.

The second error, u_i, is intended to distinguish the technical inefficiencies. Usually u_i is specified as the difference between the maximum and the actual output like $u_i = ln\, y_i^{max} - ln\, y_i$, so $u_i * 100\%$ will show the level by which the efficiency should increase in order to gain the maximum possible efficiency level or, simplifying it, it shows the level of technical inefficiency, where $u_i > 0$ means that the firm is inefficient[62]. Technical inefficiencies may be caused by factors which are under firm's control such as effort of employees. Thus, several assumptions should be made in order to evaluate the model[63]:

1. All inputs x_i are independent from u_i and v_i;
2. u_i and v_i are independent from each other and identically distributed between observations;
3. u_i has half-normal distribution, which makes the model estimable;
4. The model should be esteemed with the maximum likelihood.

From the stochastic production frontier model, which was discussed a little bit earlier, we can calculate that[64]:

$$lny_i = lny_i^{max} - u_i\,,$$
$$-u_i\ = lny_i - lny_i^{max},$$
$$\exp(-u_i) = \frac{y_i}{y_i^{max}} \in [0,1]$$

Such received ratio shows the relation between the actual output and the maximum output and shows the share from the maximum output which is now produced by the each firm. Therefore, this ratio is the technical efficiency of each firm[65]. If the ratio equals 1 it means the ideal technical efficiency level, which can not be increased.

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[62] Kumbhakar S., Lovell C. (2003), Stochastic Frontier Analysis, Cambridge University Press, 343.

[63] Kumbhakar S., Parmeter C., Zelenyuk V. (2017). Stochastic Frontier Analysis: Foundations and Advances, Working Papers 2017-10, University of Miami, Department of Economics, 103.

[64] González M. and Trujillo L. (2009). Efficiency Measurement in the Port Industry: A Survey of the Empirical Evidence. Journal of Transport Economics and Policy, Vol. 43, No. 2, 157-192

[65] Kumbhakar, S., Wang, H., Horncastle, A. (2015). A Practitioner's Guide to Stochastic Frontier Analysis Using Stata. Cambridge: Cambridge University Press. 556.

In general, stochastic frontier model is made by two steps: at first, the parameters of the model should be estimated, then in the second step inefficiency value can be calculate through the mean value. Let’s take a closer look to the each of the step.

Winsten[66] proposed the correlated ordinary least square (COLS) estimator of the model. The idea is similar with ordinary least square (OLS) method: we need to make an estimation of production frontier function lny_i, which comes from the estimated coefficients of the model. Then the production frontier is shifted above the all observations below. These 2 steps helps to achieve this:

1. On the first step the simple OLS regression of lny_i as a dependent variable and $\tilde{x}$ as independent variables with constant is run:

   $$lny_i = \widehat{\beta_0} + x_i'\widetilde{\beta}' + \widehat{e_\iota}\text{ , where}$$

   - $\widehat{e_\iota}$ is the residuals of the model obtained after running OLS;
   - $\widehat{\beta_0}$ is the biased estimation of β_0 (constant) from the stochastic production frontier model;
   - $\widetilde{\beta}'$ is the consistent estimation of the coefficients $lnf(x_i;\beta)$ from the stochastic production frontier model;

   From this model the residuals $\widehat{e_\iota}$ are defined simply by the re-arrangement of the equation in the following way:

   $$\widehat{e_\iota} = lny_i - [\widehat{\beta_0} + \widetilde{x}_i'\widetilde{\beta}'],$$

   Here, the value of residuals can be either negative or positive and equality to zero is also possible.

2. On the second step, the residuals of the model $\widehat{e_\iota}$ are corrected by the maximum of $\widehat{e_\iota}$ in order to adjust the observation from above with the production function. Then the residuals have the following form:

   $$\widehat{e_\iota} - \max(\widehat{e_\iota}) = lny_i - [\{\widehat{\beta_0} + \max(\widehat{e_\iota})\} + x_i'\widetilde{\beta}'] \leq 0\text{, where}$$

   - $[\{\widehat{\beta_0} + \max(\widehat{e_\iota})\} + x_i'\widetilde{\beta}']$ – estimated frontier function;
   - $\widehat{u_\iota} \equiv -(\widehat{e_\iota} - ma\,x(\widehat{e_\iota})) \geq 0$, where $\widehat{u_\iota}$ is the inefficiency of the model.

   Therefore technical efficiency of each observation can be estimated as $\widehat{\mathrm{TE}_\iota} = \exp(-u_i)$.

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[66] Winsten C. (1957). Discussion on Mr. Farell’s Paper. Journal of the Royal Statistical Society. Series A (General), 120, 282-284

3.3 Empirical model specification

As it was discussed in the research design, for the modeling of relationship between the container terminal handling capacity and infrastructure variable, we need to identify the set of infrastructure characteristics which will be used as inputs in the model. All chosen variables are based on the best practices discovered in the literature review and the interview with experts.

The choice of the variables which will be a basis for the model design directly influences the level of reliability and accuracy of the model and outcome discovered. Therefore, all variables should be aligned with the main purpose of the work. Because the container port activities mainly rely on the technical characteristics and special sophisticated equipment rather than on labor, all inputs and outputs in the model should reflect the majority of processes conducted in port.

There are different factors which may be used as inputs for the model, but regarding output there is the most widely accepted and understandable indicator of container port output - throughput. In the shipping industry throughput is always related to the result of using port facilities and services, and throughput is a general metric which is used for comparing ports according to their size, the level of development and intensity of activities. Moreover, throughput of the port is universally measured, therefore, this metric is analytically appropriate for the comparison among different container ports and terminals. Normally, twenty-foot equivalent (TEU) container is internationally used for measuring throughput in container ports.

Regarding the inputs which can be used to measure the efficiency of container terminal, there are a lot of possible combinations of inputs, which was discovered during the literature review in the first chapter (table 2.2), since the performance of the port depends on the various indicators:

1) infrastructural indicators: berthing facilities; storage facilities; cargo handling facilities; water depth; gate option; ice conditions; etc.
2) operational performance indicators: turnaround time; pre-berthing time; berth occupancy; capacity utilization; etc.
3) financial indicators: operating income; operating costs; investments; etc.
4) personnel indicators: number of personnel; net income per personnel; etc.

However, regarding to the study objectives, we should concentrate only on infrastructure characteristics. Therefore, after the thorough analysis of all variables the following set of characteristics was collected taking into account the data availability:

Table 3.1 Model specification

Variable	Type	Reference
Throughput	Output	López-Bermúdez, 2020
Nominal capacity	Inputs	Wang ,2019
Berth depth		Kutin, 2017; Monteiro, 2010
Maximum length of the quay		Zarbi, 2019; Monteir, 2010
Number of cranes		Zarbi, 2019; Monteiro, 2010
Storage area		Bo Lu, 2015
Ice condition		-
Maximum capacity of the vessel		Wiegmans, 2004
Maximum vessel deadweight		Wang, 2019
Maximum width of the vessel		-

Here we comprised the infrastructure terminal's characteristics and physical characteristics of the vessels being served in these terminals. There is a description of each included variable:

- Nominal capacity, TEU – installed maximum of capacity which limits the amount of TEUs for transshipment. In the majority cases the capacity of the yard or capacity of quay (determined by the capacity of ship-to-shore crane) determine the capacity of the whole container terminal;
- Berth depth, m – the vertical distance measured by the prospective draft of the vessel and the depth of reserves;
- Maximum length of the quay, m – the length of the physical wall where the vessel can be parked for loading/unloading activities. The length of the quay limits the size of vessel which may be accepted by the port;
- Number of cranes – number of Ship-to-Shore cranes which load and unload containers to and from the vessel;
- Storage area, thousand m – a specially designated area in a container terminal where containers are received stacked and dispatched;
- Ice condition, days free from ice convoy – the period, when the port navigation is possible due to the favorable weather conditions. This variable excludes the number of days when during the winter the ice formation period terminal needs icebreaking convoy which maintains the operational activity of the terminal;

- Maximum capacity of the vessel, thousand TEU – the total number of containers which is available for loading on the vessel at one time. The maximum capacity is constrained by the relative maximum deadweight of the vessel;
- Maximum vessel deadweight, thousand TEU – the total carrying capacity of a ship expressed in long tons on a specified draft. The deadweight tonnage includes the total weight of cargoes, fuel, water in tanks, stores, baggage, passengers, crew, and their effects;
- Maximum width of the vessel, m – widest point of the nominal waterline.

Here we have ice condition which is not the direct variable of the terminal's infrastructure. However, this factor reflects the ability of terminal to use the infrastructure. At the same time, the physical characteristics of vessels served also indirectly describes the terminal's infrastructure.

To sum up, we identified the list of infrastructure variables which will be used in the further research. As a result, we make a preliminary model specification like a starting point for this study.

3.4 Summary of Chapter 3

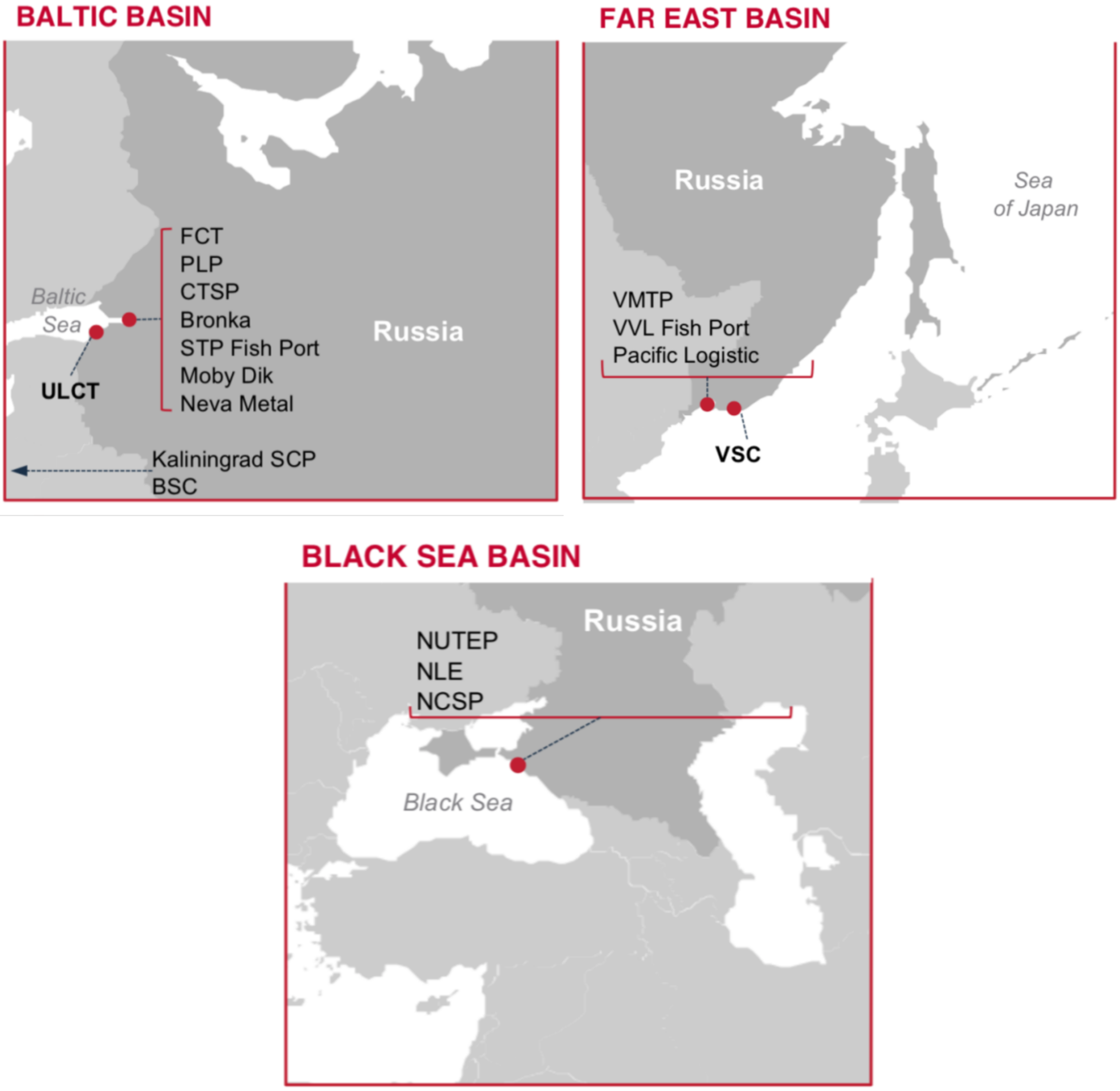
In the third chapter we made the research methodology of the empirical study. The further study is built according to the research design. The proposed analysis consists of 4 consequential stages and requires the quantitative methods. At first, we need to collect the sound database which will be used in the models. The second stage of the research requires the causality analysis using the regression model. The third stage of the study requires the use of stochastic frontier analysis for the making estimations of container terminal handling capacity. Lastly, the model on the empirical data is developed that is aimed to forecast the handling capacity of container terminals according to their infrastructure characteristics.

In this this chapter the first stage of the research was made and the infrastructure variables were proposed. According to the best practices from the literature review and availability of the data, 8 input variables were chosen: nominal capacity, berth depth, maximum length of the quay, number of cranes, ice condition, maximum capacity of the vessel, maximum vessel deadweight, maximum width of the vessel.

CHAPTER 4. EMPIRICAL RESEARCH

4.1 Data description

The data for the analysis is represented by 17 container terminals and ports, which have container specialization, and are located in Russia during the period 2012-2019. Selected terminals are the major market players and represent 3 main basins in Russia: Baltic basin, Far East basin and Black Sea basin. More detailed location of ports can be seen on the picture 4.1 and in the appendix 1:



Pic. 4.1 Main container ports and terminals in Russia

Source: author’s analysis

All information was gathered from Federal Agency for Maritime and River Transport[67] and official terminals' websites. The time frame is explained by the availability of the data.

The Baltic basin is the main gateway for imported goods to Russia and it has strategic proximity to European market and the main trade route One Belt – One Route, which is coming from China to Europe. Therefore, there is the highest concentration of the biggest container terminals. The Far East Basin has the closest location to the Asian-Pacific market and is represented by large container terminals. The Black Sea Basin is a relatively new direction in container flow, which is rapidly developing, however there is the lack of container infrastructure there. The terminal distribution by basins may be found in the table 4.1:

Table 4.1 Distribution of container terminals according to their basins

Basin	**Terminal**
Baltic basin	• Container terminal Saint-Petersburg; • First Container Terminal; • Ust-Luga Container Terminal; • Bronka; • Moby-Dik; • Neva Metal; • Sea Fish Port; • Petrolesport; • Kaliningrad Sea Commercial Port; • Baltic Stevedore Company.
Far East Basin	• Pacific Logistic; • Vladivostok Sea Fish Port; • Vostochnaya Stevedoring Company; • Commercial Port of Vladivostok.
Black Sea Basin	• Novorossiysk Commercial Sea Port; • Novoroslesexport; • Container Terminal NUTEP.

All of the mentioned ports and terminals are different in terms of their authorities, sizes and capacities of throughput which they can handle. The most convenient way to compare terminals

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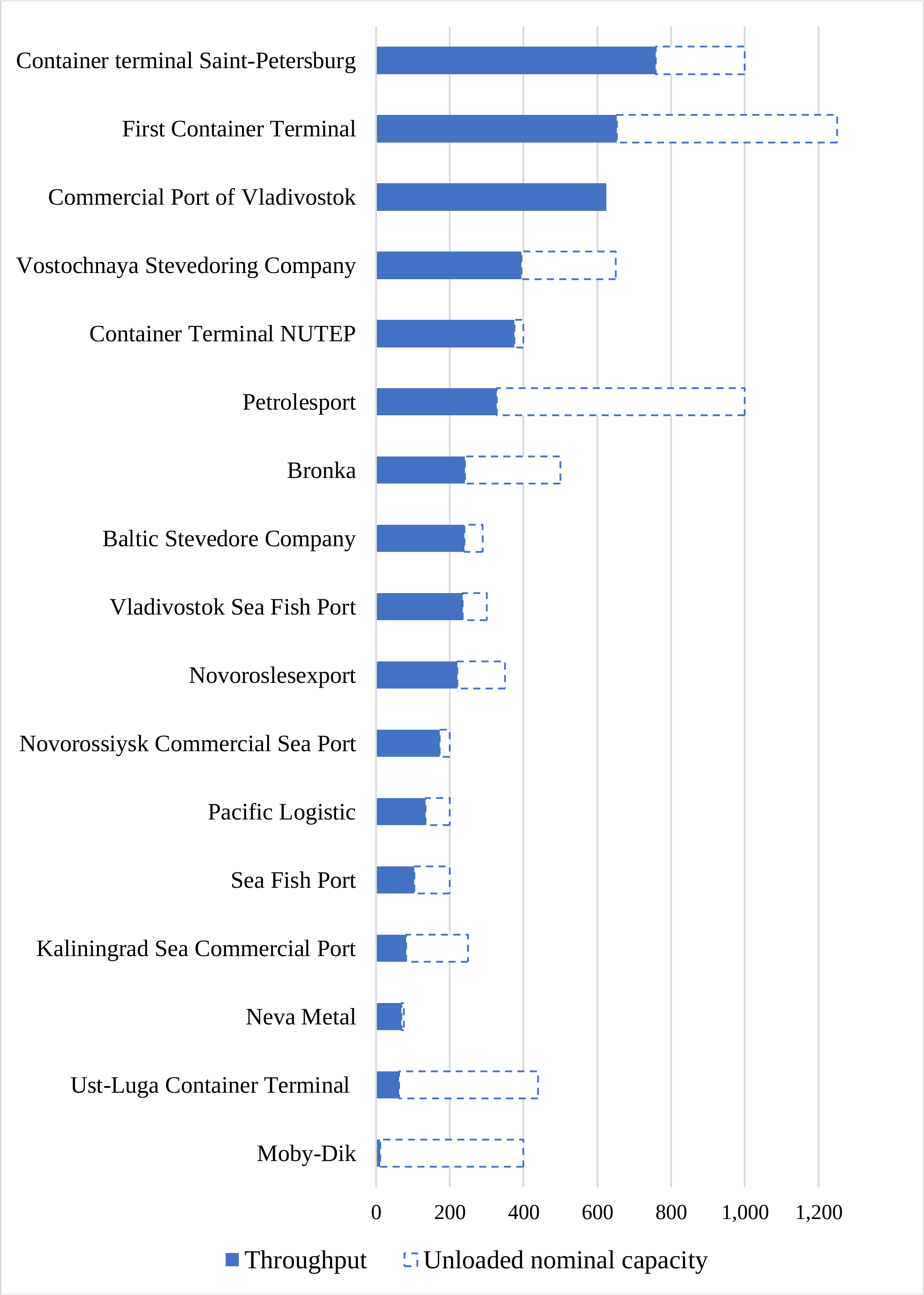
[67] Federal Agency for Maritime and River Transport. Retrieved June 4, 2020, http://www.morflot.ru/

is by their throughput (graph 4.1). According to it, Container terminal Saint-Petersburg, First Container Terminal and Commercial Port of Vladivostok may be considered as the largest container terminals in Russia since their throughput exceeds 600 thousand TEU. Then Mobi-Dik, Ust-Luga, Neva Metal, Kaliningrad Sea Commercial Port are the small terminals because they handled less than 100 thousand TEU in 2019.



Graph 4.1 Container throughput in main container terminals in 2019, thousand TEU

Source: official terminals' statistics

Nevertheless the terminals are different in terms of their sizes and capacities, they have standardized functions, activities and facilities which are inherent to any container terminal, therefore they all can be used as inputs for the modeling of efficiency.

According to descriptive statistics represented on Table 4.2, it can be seen that the terminals vary not only by the volume of throughput cargo and capacity, which is visible on the graph 3.1, but by other infrastructure characteristics. For example, storage area and length of the quay are one of the most deviated metrics among observed terminals. Moreover, ports differ by the number of days suitable for the ice-free navigation, which can be explained by the fact that all ports are located in different parts and climate zones of Russia. Berth depth and number of cranes are the least variable characteristics.

Table 4.2 Descriptive statistics of container terminals

Variable	Scale	Average	Median	Min	Max	St. dev.	Variation
Througput	1000 TEU	260.04	186.88	1.2030	1083.9	216.33	0.831
Capacity	1000 TEU	442.22	350.00	31.0	1250.0	315.50	0.713
Ice condition	Days	58.289	30.00	0.0	148.00	56.337	0.966
Free days	Days	306.71	335.00	217.00	365.00	56.337	0.183
Berth depth	m	11.496	11.500	7.5000	14.400	1.9261	0.167
Maximum length of the quay	m	235.27	254.70	131.00	320.80	59.982	0.254
Number of cranes	Number	4	5	2	8	1.603	0.351
Storage area	1000 sq.m	219.28	183.44	28.930	677.28	188.62	0.860

Another thing which is worth examining is the characteristics of the vessels which can be served in observed container terminals (Table 4.3). The vessel vary a lot in their parameters since the ports of their calls are different too. Therefore, there are a wide range of vessels which come to Russian container ports and their sizes should correspond with the port characteristics. For example, the maximum vessel deadweight should not exceed the berth depth.

Table 4.3 Descriptive statistics of vessels served in container terminals

Variable	Scale	Average	Median	Min	Max	St. dev.	Variation
Maximum capacity of the vessel	1000 TEU	3.28	3.00	1.00	6.00	1.59	0.486
Maximum vessel deadweight	m	10.64	11.00	7.0000	14.00	1.82	0.171
Maximum width of thevessel	m	28.99	30.00	16.80	42.00	6.52	0.225

For the further model specification we have chosen 9 variables, which represent different parts of terminals' facilities: nominal capacity, berth depth, maximum length of the quay, number of cranes, storage area, maximum capacity of the vessel, maximum vessel deadweight, maximum width of the vessel, ice condition.

All variables which potentially should be included in the model were described in paragraph 3.3, so there is the summary of model specification in terms of variables:

Table 4.4 Variables specification

Type of variable	Variable	Label	Measurement
Output	Annual throughput	Y	Thousand TEU
Inputs	Nominal capacity	X_1	Thousand TEU
	Berth depth	X_2	Meters
	Maximum length of the quay	X_3	Meters
	Number of cranes	X_4	Quantity
	Storage area	X_5	Thousand square meters
	Ice condition	X_6	Days
	Maximum capacity of the vessel	X_7	Thousand TEU
	Maximum vessel deadweight	X_8	Thousand TEU
	Maximum width of the vessel	X_9	Meters

So as we can see from the table 4.4, the model has one dependent variable Y, nine independent factors representing the efficiency of terminals' activities (X_i, i=1..9).

4.2 Cause and effect analysis

This stage of the study is aimed to show the causality between the throughput cargo volumes in the Russian container terminals and the infrastructure characteristics of the ports. As a result, we may have the list of parameters which influence the throughput capacity of the port.

At the beginning, the starting point for the empirical research was the linear regression built with all available variables (table 3.2) which were transformed in natural logarithmic form. The logarithmic form was chosen because of the notion that the logarithmic regression is the more general type of the regression and according to methodology we construct the Cobb-Douglas function. Cobb-Douglas function reflects the current technology achieved and connects the production result, throughput in our case, with the required resources, infrastructure variables. Chosen regression was estimated by the Ordinary Least Square method.

According to these premises stated above the following model came:

$$\mathit{Ln\_throughput} = 10.78 + 1.14 * \mathit{ln\_Utilizationofcapacity} - 2.54 * \mathit{ln\_Berthdepth} + 0.67 * \mathit{ln\_Maximumlengthofthequay} + 0.80 * \mathit{ln\_Numberofcranes} - 0.20 * \mathit{ln\_Storagearea} + 0.31 * \mathit{ln\_Maximumcapacityofthevessel} + 2.49 * \mathit{ln\_Maximumvesseldeadweight} - 2.74 * \mathit{ln\_Maximumwidthofthevessel}$$

Here we do not include the ice condition of the terminals because in this model we test the influence of infrastructure and physical characteristics inherent to port and vessels. From this side, the ice condition variable may be considered as a stochastic component, since the port can not influence the period of navigation during the winter season.

Then we are going to evaluate the quality of the model by using the detailed statistics of the model:

Table 4.5 Model 1

Dependent variable	l_lthroughput			
Independent variables	*Coef.*	*St. error*	*t-statistics*	*P-value*
const	10.781	2.201	4.896	<0.0001 ***
l_Nominalcapacity	1.143	0.139	8.212	<0.0001 ***
l_Berthdepth	−2.541	1.255	−2.024	0.0453 **
l_Maximumlengthofthequay	0.671	0.409	1.639	0.1040
l_Numberofcranes	0.801	0.170	4.698	<0.0001 ***
l_Storagearea	−0.205	0.114	−1.795	0.0754 *
l_Maximumcapacityofthevessel	0.308	0.318	0.9694	0.3345
l_Maximumvesseldeadweight	2.494	1.430	1.743	0.0840 *
l_Maximumwidthofthevessel	−2.741	0.593	−4.618	<0.0001 ***

Regression statistics:

N observations	132
R-square	0.610
F(4, 13)	21.733
Adj. R-square	0.582
P-value	1.43e-19
AIC	202.285

Nevertheless the entire model is significant according to F-statistics and the adjusted R-square is relatively high (up to 60%), the overall model shows pretty poor approximation. Poor quality of the model can be observed by the coefficients before variables, which exceed 1, and the unexpected signs before the coefficients which contradict basic economic postulates. For example, ln_Storagearea and ln_Berthdepth variable have a negative sign. However, according to the logical and economic expectation, the storage area and the depth of the berth should positively influences the throughput of the port because the storage area provides the port with more place to store more containers and with the ability to handle bigger vessels.

Moreover, there are several insignificant variables such as Maximum capacity of the vessel and Maximum vessel deadweight is almost insignificant or has the slight influence on the throughput. It gives us the understanding that all vessel characteristics do not explain the capacity of the port. This hypothesis comes from the understanding of port infrastructure parameters. For example, the maximum vessel deadweight can not directly influence the capacity of the container terminals because it is limited by the berth depth. Conceptually, if the berth depth is not enough, the port would not service the vessels with the deadweight exceeding the maximum berth depth. The same thing is with maximum capacity of the vessel. If the quay length and berth depth are not enough to serve big vessel, for example, New Panamax or Ultra Large Container Vessel, it means that the capacity of the vessel can not impact on the capacity of the port. Therefore, berth depth and the maximum length of the quay are main bottlenecks which define the parameters of the vessels being handled in the port.

Having this understanding we dropped some variables from the model 1 and made a next step in the model improvement (Table 4.6).

Table 4.6 Specification of Model 2 and Model 3

Type of variable	Variable	Label	Measurement
Output	Annual throughput	Y	Thousand TEU

Inputs	Berth depth	X_1	Meters
	Maximum length of the quay	X_2	Meters
	Number of cranes	X_3	Quantity
	Storage area	X_4	Thousand square meters
	Ice condition	X_5	Days

Here we have the list of 5 variables which were proceed for the next research. It has to be remarked, that only variables from X1 to X4 can be considered as infrastructure characteristics of the terminals and X5 reflects the opportunity to use the terminal’s infrastructure. Therefore, the model was run again with and without X5.

The data set is represented by the 17 different terminals which differ in terms of their sizes and infrastructure. One of the main deviated characteristics is the length of the quay and the storage area. This aspect may also create shifts in the data and leads to the poor goodness of the model. So we normalized the data in order to weaken the fact of different port scales using the following formula:

$$\frac{actual\ value\ of\ the\ infrastrucutre\ characteristic_i}{maximum\ value\ of\ the\ infrastrucutre\ characteristic_i}.$$

Then the second model with normalized data and without the ice condition influence was constructed:

$$Ln\_throughput = -0.72 + 0.18*ln\_Berth\_depth\_norm + 0.99*ln\_Quay\_length\_norm + 0.08*ln\_crane\_norm - 0.21*ln\_Storage\_norm$$

Then we are going to evaluate the quality of the model by using the detailed statistics of the model(Table 4.7):

Table 4.7 Model 2

Dependent variable	l_throughput			
Independent variable	*Coef.*	*St. error*	*t-statistics*	*P-value*
const	−0.715	0.529	−1.351	0.1790
ln_storage_normT	0.210	0.075	2.791	0.0060 ***
ln_quay_length_norm	0.995	0.381	2.610	0.0101 **
ln_berth_depth_norm	0.188	0.393	0.4791	0.6327
ln_cranes_norm	0.083	0.063	1.323	0.1880

Regression statistics:

N observations	132
R-square	0.579
F(4, 13)	45.113
Adj. R-square	0.566
P-value	9.01e-24
AIC	360.579

Comment: T *“norm” is the name of the variable means that the data was normalized*

The model is overall significant according to F-test. The adjusted R-square is up to 60% like it was in the first model. Coefficients are less than 1 and there is no contradicting sign of coefficients. As a result, the model has a better fit than the first model. However, some coefficients became insignificant such as the berth depth and the number of cranes. In practice, this variables are important in the defining the handling capacity of the port, so we can conclude that the model still needs improvement.

Here we conducted the same model but with the impact of ice condition:

$$\mathit{Ln\_throughput} = -3.93 + 0.26*\mathit{ln\_Berth\_depth\_norm} + 0.93*\mathit{ln\_Quay\_length\_norm} + 0.25*\mathit{ln\_crane\_norm} - 0.21*\mathit{ln\_Storage\_norm} + 0.54*\mathit{ln\_Ice\_condition\_free\_days}$$

The model output is the following (Table 4.8):

Table 4.8 Model 3

Dependent variable	l_throughput			
Independent variable	*Coef.*	*St. error*	*t-statistics*	*P-value*
const	−3.932	2.629	−1.496	0.1372
ln_storage_n	0.2082	0.0791	2.631	0.0095 ***
ln_quay_length_n	0.932	0.385	2.420	0.0169 **
ln_berth_depth_n	0.258	0.411	0.628	0.5310
l_Ice_condition_free_days	0.541	0.424	1.275	0.2046
l_Numberofcranes	0.258	0.202	1.279	0.2032

Regression statistics:

N observations	132
R-square	0.587
F(5, 130)	36.964
Adj. R-square	0.571
P-value	2.00e-23
AIC	360.073

Overall, the adjusted R-square increased and the model is significant. But with the adding of the ice condition, the model is worse according to the information criteria. Moreover, the factor of ice condition is insignificant in the model which tells us that there is no influence of period of navigation on the throughput. Literally, it is controverting because during the winter period there are fewer calls to port and fewer vessels can be served due to the absence of special requirement for the winter navigation. So, such model specification does not show the expected causality.

So we tried 3 different models which have poor goodness and all of them need improvements. From this point we can conclude that the liner form of the regression is not suitable here and it does not show stable and reliable causality between the container terminal capacity and the infrastructure characteristics of the port.

One possible explanation of such results is that the infrastructure characteristics of container ports are tend to change only in the long-term perspective. In other words, it means that the data reflecting the infrastructure variables are majorly constant during the observation period since container terminals are capital investment driven projects. Therefore, the length of the quay or the storage area may stay the same for many years since they require high investments to be changed. Because of that the infrastructure characteristics do not play the role of variables, they should be treated as parameters which are included in the model. Thus, it was decided to construct the infrastructure quality index:

$$\begin{aligned} Infrastrucutre\ quality\ index_i \\ &= normalized\ berth\ depth\ +\ normalized\ length\ of\ the\ quay \\ &+\ normalized\ number\ of\ cranes\ +\ normalized\ storage\ area \end{aligned}$$

It is also should be mentioned, that all parameters included into the infrastructure index should be normalized in order to nihilate the effect of different terminals’ sizes, which was discussed earlier.

Based on this knowledge, we assume that throughput of the container terminals are determined by 2 main variables:

Table 4.6 Specification of Model 4

Type of variable	Variable	Label	Measurement
Output	Annual throughput	Y	Thousand TEU
Inputs	Ice conditions	X_1	Days
	Infrastructure quality index	X_2	-

The first variable, ice condition reflects the period of ice-free navigation and shows the number of days with the access to the terminals' infrastructure and limits the ship calls during the winter.

The second variable is the infrastructure quality index, which consists of 4 infrastructure characteristics:

1. Berth depth;
2. Length of the quay;
3. Number of cranes;
4. Storage area.

This variables are mainly constant during the observed period of 2012-2019 years, but they are different for each terminal. Therefore, the infrastructure quality index was introduced.

The new functional form of the model will be the following:

$$\ln\left(Throughput_i\right) = a + \beta * \left(Infrastrucutre\ quality\ index_i\right) * \ln\left(Ice\ condition\right),\quad i = 1..17$$

where:

a – constant;

β – coefficient of elasticity;

$Infrastrucutre\ quality\ index$ – parameter, which comprises 4 infrastructure normalized variables (Berth depth; Length of the quay; Number of cranes; Storage area);

$Ice\ conditions$ - number of days when port is able to serve vessels during the navigation period.

Therefore, the equation is re-written in the following way:

$$\ln(Throughput) = a + \beta * (Berth\ depth_i + Length\ of\ the\ quay_i + Number\ of\ cranes_i + Storage\ area_i) * \ln\left(Ice\ conditions_i\right),\ i = 1..17$$

Then:

$$Throughput_i = \left(Ice\ conditions_i\right)^{\beta*(Infrastructure\ index_i)},\ i = 1..17$$

Having this functional form, we constructed the cause and effect model:

$$Throughput = (Ice\ conditions)^{0{,}328*(Infrastrucutre\ index)}$$

The output of the model is following:

Table 4.7 Model 4

Dependent variable	l_throughput			
Independent variable	*Coef.*	*St. error*	*t-statistics*	*P-value*
Infrastructure_index* _ln_free_days	0.328	0.004	67.70	<0.0001 ***

Regression statistics:

N observations	132
R-square	0.985
F(1, 131)	4583.769
P-value (F)	8.3e-104
AIC	342.515

According to the regression statistics, this model has the best specification among others which we assessed earlier. Overall, the model is significant due to F-test and the variable is significant on the 99% level. The model has R-square 99%, which means that the 99% of the throughput variation is explained by the variable, which consists of the infrastructure index and the number of days when the port is able to serve vessels, and the only 1% is explained by errors. This means, that we achieved almost ideal model approximation and proved the causality between the terminal’s throughput and selected variables.

4.3 Construction of production frontier model

After finding the appropriate configuration of the model which shows the clear causality between the handling terminal capacity and its infrastructure and accessibility of the port, we proceed with the second stage of the research –construction of production frontier model. The aim of this stage is to estimate the technical efficiency of observed container terminals and make projections of their throughput handling capacity. For this purpose the production frontier should be built.

As the appropriate model configuration was defined in the first stage, the same configuration will be applied for the SFA: the ice conditions; days and the infrastructure of the terminals will be input variables and terminals’ throughput will be output variable.

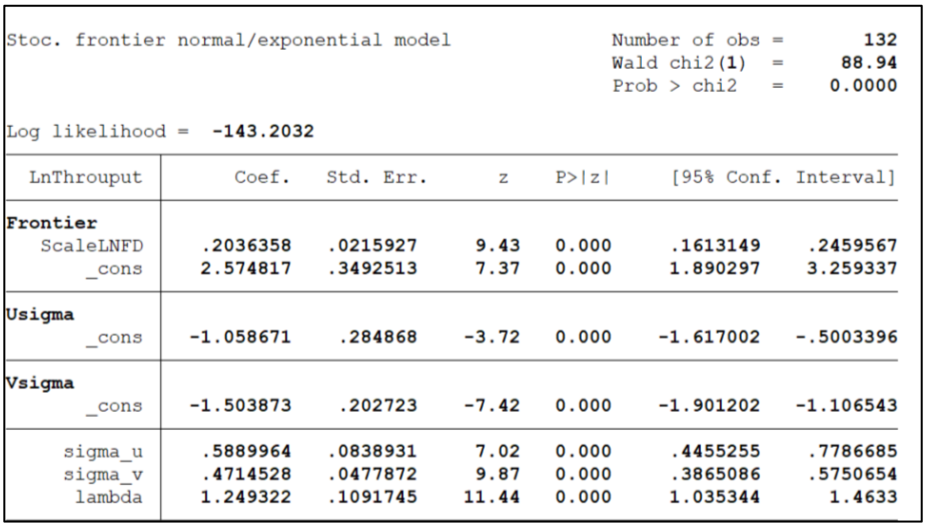
According to the methodology discussed in 3.2, the model would have the following equation:

$\ln(throughput_i) = \beta(Infrastructure\ index_i) * ln\ (Ice\ conditions) + v_i - u_i$, where

- v_i –random errors representing stochastic noise;
- u_i – technical inefficiencies.

This parametric method is sensitive to the distribution type chosen for the model, therefore, the different models would be constructed.

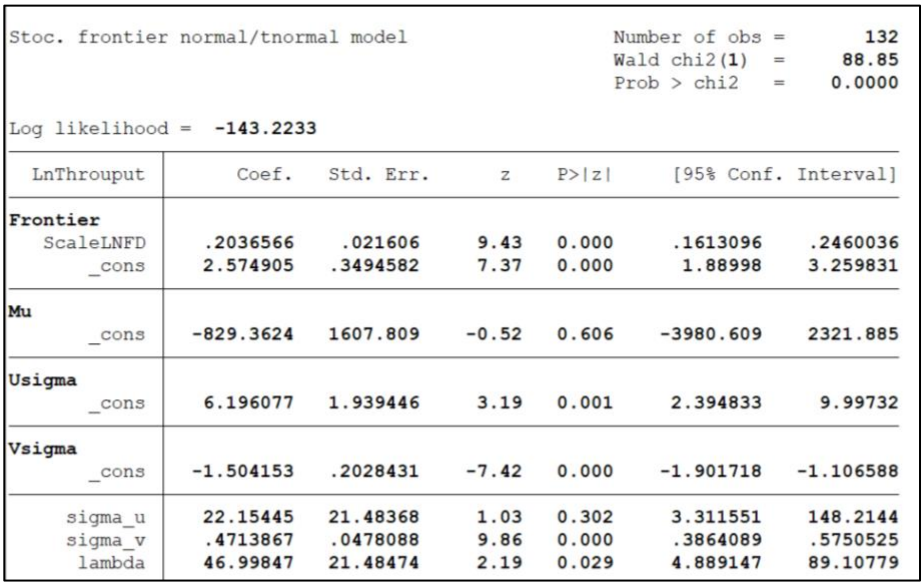
Having all premises in mind, we used statistical software STATA 14.0 for the production frontier estimation. The models were constructed with the different distribution functions: exponential, truncated-normal and half-normal in order to find out the best model specification. The output of the models may be seen below:



```
Stoc. frontier normal/exponential model             Number of obs =        132
                                                    Wald chi2(1)  =      88.94
                                                    Prob > chi2   =     0.0000

Log likelihood =  -143.2032
------------------------------------------------------------------------------
  LnThrouput |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
Frontier     |
   ScaleLNFD |   .2036358   .0215927     9.43   0.000     .1613149    .2459567
       _cons |   2.574817   .3492513     7.37   0.000     1.890297    3.259337
-------------+----------------------------------------------------------------
Usigma       |
       _cons |  -1.058671     .284868   -3.72   0.000    -1.617002   -.5003396
-------------+----------------------------------------------------------------
Vsigma       |
       _cons |  -1.503873     .202723   -7.42   0.000    -1.901202   -1.106543
-------------+----------------------------------------------------------------
     sigma_u |   .5889964   .0838931     7.02   0.000     .4455255    .7786685
     sigma_v |   .4714528   .0477872     9.87   0.000     .3865086    .5750654
      lambda |   1.249322   .1091745    11.44   0.000     1.035344      1.4633
```

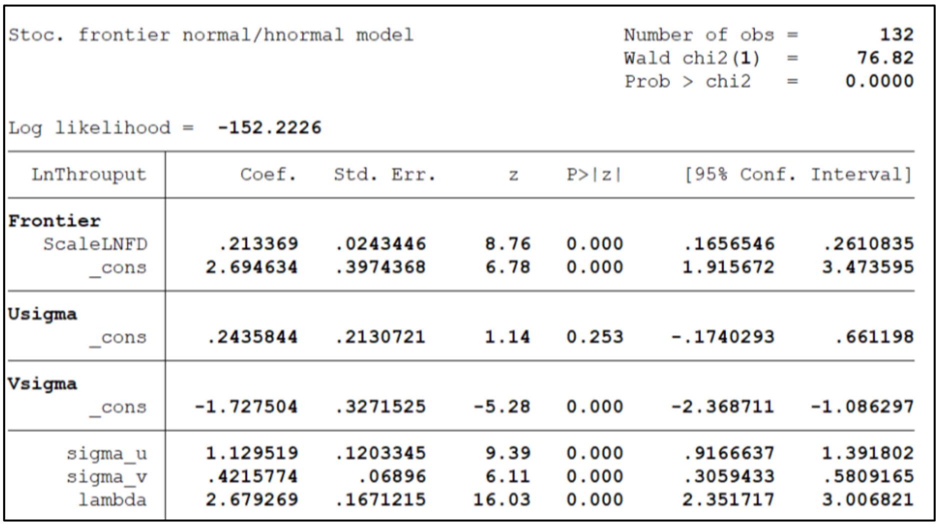
Pic.4.2 SFA model with exponential distribution



```
Stoc. frontier normal/tnormal model                 Number of obs =        132
                                                    Wald chi2(1)  =      88.85
                                                    Prob > chi2   =     0.0000

Log likelihood =  -143.2233
------------------------------------------------------------------------------
  LnThrouput |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
Frontier     |
   ScaleLNFD |   .2036566     .021606     9.43   0.000     .1613096    .2460036
       _cons |   2.574905   .3494582     7.37   0.000      1.88998    3.259831
-------------+----------------------------------------------------------------
Mu           |
       _cons |  -829.3624   1607.809    -0.52   0.606    -3980.609    2321.885
-------------+----------------------------------------------------------------
Usigma       |
       _cons |   6.196077   1.939446     3.19   0.001     2.394833     9.99732
-------------+----------------------------------------------------------------
Vsigma       |
       _cons |  -1.504153   .2028431    -7.42   0.000    -1.901718   -1.106588
-------------+----------------------------------------------------------------
     sigma_u |   22.15445   21.48368     1.03   0.302     3.311551    148.2144
     sigma_v |   .4713867   .0478088     9.86   0.000     .3864089    .5750525
      lambda |   46.99847   21.48474     2.19   0.029     4.889147    89.10779
```

Pic.4.3 SFA model with truncated-normal distribution



```
Stoc. frontier normal/hnormal model                 Number of obs =        132
                                                    Wald chi2(1)  =      76.82
                                                    Prob > chi2   =     0.0000

Log likelihood = -152.2226
------------------------------------------------------------------------------
  LnThrouput |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
Frontier     |
   ScaleLNFD |    .213369   .0243446     8.76   0.000     .1656546    .2610835
       _cons |   2.694634   .3974368     6.78   0.000     1.915672    3.473595
-------------+----------------------------------------------------------------
Usigma       |
       _cons |   .2435844   .2130721     1.14   0.253    -.1740293     .661198
-------------+----------------------------------------------------------------
Vsigma       |
       _cons |  -1.727504   .3271525    -5.28   0.000    -2.368711   -1.086297
-------------+----------------------------------------------------------------
     sigma_u |   1.129519   .1203345     9.39   0.000     .9166637    1.391802
     sigma_v |   .4215774     .06896     6.11   0.000     .3059433    .5809165
      lambda |   2.679269   .1671215    16.03   0.000     2.351717    3.006821
```

Pic.4.4 SFA model with half-normal distribution

Among all of these three models, the third model with the half-normal distribution has the best fit according to the Log-likelihood test. According to p-value, which is 0, we may conclude that there is an evidence that the selected inputs definitely impact the dependent variable and as a consequence the terminal’s performance.

Then we are going to speak about the third model only. This model constructs the production frontier of empirical handling capacity according to the infrastructure parameters. Having the production frontier, we may estimate empirical handling capacity and the technical efficiency which each port reaches for the last 8 years:

Table 4.8 Average technical efficiencies of container terminals in 2012-2019

Terminal	**Technical efficiency**
Container terminal Saint-Petersburg	82%
First Container Terminal	80%
Container Terminal NUTEP	73%
Commercial Port of Vladivostok	72%
Moby-Dik	71%
Petrolesport	70%
Baltic Stevedore Company	65%

Pacific Logistic	61%
Novoroslesexport	61%
Vladivostok Sea Fish Port	58%
Novorossiysk Commercial Sea Port	58%
Neva Metal	56%
Vostochnaya Stevedoring Company	56%
Ust-Luga Container Terminal	48%
Sea Fish Port	47%
Kaliningrad Sea Commercial Port	35%
Bronka	34%

Source: author's calculations using STATA

Container terminal Saint-Petersburg and First Container Terminal which are located in the Baltic Basin are the market leaders in terms of the handled throughput. Moreover, they are one of the most modern terminals in Russia and possess the affluent infrastructure characteristics. Therefore, their highest technical efficiency estimations 82% and 80% respectively can be proved by the up-to-date Ship-to-Shore cranes and effective terminal activities and processes, mainly, storage. For example, Container terminal Saint-Petersburg has the smaller storage area than First Container Terminal, and is still more efficient.

Container Terminal NUTEP which is in the Black Sea Basin is a leader in its region and shows solid 73% of technically efficient utilization of empirical capacity. Although, the ports such as Novoroslesexport and Novorossiysk Commercial Sea Port from the same basin could reach only 61% and 58% respectively. It should also be admitted that the technical efficiency of Novoroslesexport and Novorossiysk Commercial Sea Port is a result of their re-profiling. Initially, these ports accepted the general cargo and timber and then were re-profiled to container cargo. So here we may see how their infrastructure is suitable for the serving containers.

Commercial Port of Vladivostok is the most efficient terminal in the Far East Basin. Vladivostok Sea Fish Port was also re-profiled and reached 58% of technical efficiency.

Surprisingly, that all reprofiled ports are on the same level of technical efficiency which ranges from 58% to 61% and only Sea Fish Port is below 50%. It means, that their initial infrastructure characteristics were not supposed to handle containers, thus they have such low rates of technical efficiency. It may be caused by non-optimal utilization of cranes or the lack of necessary storage areas.

4.4 Modeling of handling capacity

With the help of SFA modeling we empirically estimated the level of technical efficiency and handling capacity which a terminal really could achieve according to its infrastructure characteristics and ice conditions in observed container terminals in Russia. Based on these projections we are able to make the forecast of technical efficiency and handling capacity of ports with any kind of infrastructure configuration.

For this purpose we construct the cause and effect regression function of Cobb-Douglas:

$$Ln(Handling\ capacity)=a*Ln(Infrastructure\ index)+b*Ln(Free\ days)$$

Where a and b are the elasticity coefficients .

Having this model, we achieved the functional relationship:

$$Ln(Handling\ capacity)=0.43*Ln(Infrastructure\ index)+0.63*Ln(Free\ days)$$

The output of the model is the following:

Table 4.8 Projections of technical efficiency

Dependent variable	*Ln(Handling capacity)*			
Independent variable	*Coef.*	*St. error*	*t-statistics*	*P-value*
Ln(Infrastructure index)	0.427	0.335	1.272	0.205
Ln(Free days)	0.629	0.059	10.626	0.000

Regression statistics:

N observations	132
R-square	0.988
F(1, 131)	2708.769
P-value (F)	4,4645E-106

The model is significant according to F-test. All variables is also significant according to p-value and it means, that they do impact the technical efficiency of container terminals. The sum of regression coefficients is almost 1, which is the evidence of the good model fit.

Making the component analysis, we have that the empirical handling capacity is 40% dependent from infrastructure index and 60% dependent from the days, when port is able to work without any limitations such as ice-conditions.

This functional relation may be used in container terminals in order to define what real handling capacity a terminal could achieve with the given infrastructure parameters. As a result, this model can be used as a decision support tool for the terminal authorities. Having the understanding what configuration of terminal parameters would lead to the certain real capacity of the terminal, management can make a decision whether to re-profile a terminal or not.

In other words, among all infrastructure parameters, the depth of the berth and the length of the quay are the characteristics which can be hardly changed. Moreover, the days when ports can work without any limitations are also not under terminal's control and depend on the geographical location of the terminal and the climate in this region. Therefore, the number of cranes and the storage area are the only characteristics which can be variable. However, they need huge capital investments. So by trying different configuration of these 2 variables, management could evaluate the empirical capacity which they need for the feasible terminal operations.

4.5 Discussion of results

4.5.1 Academic contribution

This masher thesis possesses the valuable academic contribution for the study of container terminal efficiency. First of all, the four-stage design of the container terminal handling capacity was developed. It provides the achievement of the main goal of this work. Moreover, during the cause and effect modeling of relationship between the container terminals' throughput and infrastructure characteristics it was revealed that variables reflecting the infrastructure characteristics are mainly constant in time, therefore they should be considered as parameters for the model. Thus, the infrastructure quality index was proposed for the first time in such type of the research.

Infrastructure quality index includes the normalized data on the berth length, the length of the quay, storage are and the number of cranes. Such model specification helps to achieve good fit of the model which proved the relationship between the throughput and infrastructure characteristics.

Then the production frontier of Russian container terminals was constructed using the Stochastic Frontier Analysis. It allowed to make the projections of container terminal handling capacity and the technical efficiencies of observed container terminals. Moreover, we can estimate current level of terminals' utilization and make conclusions regarding their performance.

Lastly, the empirical model for the estimation of handling capacity under specific terminals' infrastructure variables and ice conditions was firstly introduced. It forecasts the container terminal handling capacity and the level of terminals' utilization which can be achieved with the current infrastructure characteristics. The application of this model will be further discussed in 4.5.2 chapter.

4.5.2 Managerial implication

The study provided has a potential to be approbated in the managerial decisions in the container terminals. For instance, due to the change in the demand: decrease in transportation of the non-container cargo and the increase in transportation of containers, some ports and terminals are decided to be re-profiled and serve containers. As an example, Fish Sea Port and Vladivostok Fish Sea Port were focused on the transshipment of fish products, but when the fish catch decreased in the region, terminals were adopted for the container service. Apart from this, Novorossiysk Commercial Sea Port used for general cargo and Novoroslesexport used for timber faced the same situation as fish ports and were partially and totally re-profiled to handle containers. However, as was discovered during the production frontier construction, these ports work with the maximum 60% of utilization of their handling capacity.

So there is the evidence that more and more ports are re-profiled to the container terminals due to the containerization tendency and consequently, the rising demand for container transportation. For this purpose the management needs to know the potential container terminal handling capacity obtained from the current infrastructure characteristics and the potential level of its utilization in order to make decision about the change of specialization. The knowledge of this information supports the feasibility analysis of port re-profiling.

Therefore, the model of casual relationship between the handling capacity and infrastructure characteristics could project the estimations of handling capacity under specific terminals' infrastructure variables and ice conditions. So by varying the possible changes in infrastructure parameters, for example, the number of cranes or storage area, port authorities can find out what investment in what part of terminal's infrastructure should be done in order to provide required container terminal handling capacity. As a result, the model evaluates the effects of port's reprofiling.

4.5.3 Limitations and further research

There are some limitations in the master thesis that should be taken into account in further research.

Firstly, in this work we considered only infrastructural characteristics that influence the container terminal handling capacity. Such scope of variables is explained by the availability and reliability of the data. However, infrastructural aspect is one of the possible drivers influencing the handling capacity. Therefore, it is important to continue the investigation of factors that impact handling capacity. Thus, in order to reach more accurate modeling of container terminal handling capacity other fulfilling variables should be considered. For example, current dataset can be extended by such factors as personnel, number of equipment (number of yard cranes, reach stackers, forklifts, etc.), service characteristics (frequency of calls, time of vessel loading/unloading, tariffs, etc.). So having this data, the model can be complemented by different variables.

Secondly, this study focuses only on the one type of ports – container terminals. However, non-container ports have the similar operational activities and require the same resources. Thus, their models of providing services are comparable to the container terminals. Therefore, the research can be extended by the examination of the applicability of the obtained model for non-container ports and terminals.

Last but not least, the research is also relevant for the related industries for maritime transportations where handling capacity is also significant for business needs. These industries are: railway transportation and air transportation. For them, the projections of real capacity of the dry port or airport and its utilization matter in terms of business standpoint and determine the real amount of cargo that can be transported.

Conclusion

Due to the shifts in the demand on the cargo transportation: decrease in non-container cargo and increase in container cargo, container terminals increased their role in the international logistics chains and act as trade facilitators in the regions and countries. However, there is also a lack of container handling capacity at current ports in Russia in a short term. Therefore, terminal managers of non-container ports started to re-profile ports into container terminals, since there is a long-term trend of containerization of goods. Thus, the hot topic for the management is to define what infrastructure characteristics a terminal should possess in order to be re-profiled.

The study was aimed to make a design and application of analytical models for measuring an impact of the infrastructural variables on the container terminals handling capacity. The goal of the master thesis filled out the research gap – the absence of studies on infrastructure variables which influence the handling capacity of the terminal. For this purpose the list of objectives was met on the rolling basis of this work.

At the beginning the concept of container terminal handling capacity was operationalized. In this research we consider handling capacity as the real maximum throughput which can be handled in the terminal accounting for existing practices of serving vessels under realistic operating conditions. Therefore, terminal authorities needs to know real throughput that is lower than the nominal capacity in order to manage terminal's development.

For the modeling of container terminals handling capacity 17 major container terminals in Russia were taken. Then the sound database was collected. The panel data includes infrastructure characteristics of terminals from the period of 2012-2019.

In this study we provided the causality model of relationship between throughput of the container terminals and their infrastructure variables. For this purpose the infrastructure quality index was proposed that was treated as parameter since the infrastructure characteristics do not change. It comprises normalized data of berth depth, length of the quay, number of cranes and storage area. Such model specification helps to achieve reliable quality of the model.

Then the empirical container handling capacity and technical efficiency rates for selected container terminals were estimated by constructing production frontier with the help of Stochastic Frontier Analysis. These projections are the evidence of current terminals performance. Moreover, on the basis of empirical handling capacities the causal model of relation between technical efficiency of the terminals and the infrastructure variables was constructed. Having reliable model with the good fit we can make forecasts of empirical container terminal handling capacity according to infrastructure characteristics.

As a result of the study, the obtained model can be used as a tool supporting the managerial decisions. For example, there is the evidence that more and more ports are re-profiled to the container terminals due to the containerization tendency and the rising demand for container transportation. For this purpose the management needs to know the potential container terminal handling capacity obtained from the current infrastructure characteristics and the potential level of its utilization in order to make decision about the change of specialization.

Regarding further research, the study can be extended by other factors influencing the container terminal handling capacity such as personnel, services and other qualitative characteristics. Moreover, the scope of the model can be broaden: it can be used for handling capacity projections in non-container terminals and ports or for other related industries such as railway and air transportations.

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Appendix

Appendix 1. Location of selected container terminals in Russia