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Investigating the Sustainable Impact of Seaport Infrastructure Provision on Maritime Component of Supply Chain

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Abstract: The aim of the research is to identify and quantify the direct economic effects resulting from the improved seaport nautical access and capacity expansion. This case study considers a regional port located in the Baltic sea and relates to port users, i.e., shipping operators and shippers. The effects were identified for maritime transport by comparing transport performance in two scenarios: with-the-investment and without-the-investment. Incremental calculus addresses freights (containers, dry bulk, and cereals) traded to and from the given port, changes in size of vessels, and the shipping route alternatives vis-a-vis adjacent ports in the range. Sustainable impact concerns generalized maritime transport cost, i.e., shipping operating costs and port-to-port transit time, as well as energy consumption and external costs of maritime shipping. To capture effects, daily and unit dry bulk, as well as container shipping cost, values of time, and marginal external costs were revealed in freight sea transport. As investigated, shipping operators and shippers will benefit from the reduction in ships' operating (including ships' fuel cost savings) and time cost, while the community will enjoy the reduction in externalities. However, the main economic effect is the reduction in shipping operating cost resulting from the increased vessel size (economies of scale).

Keywords: port; investment; impact; sustainability; energy savings; maritime transport; supply chain component

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1. Introduction

In general, a seaport can be described as a place where two domains—the land traffic and maritime traffic—contact and merge with each other. The key role that the seaport plays is to ensure the continuity between two transport systems that cross two spaces with different characteristics [1], which has operations in a foreland, the port proper, and hinterland, thus constituting a (sub) supply chain that brings goods from/to the seaside and to/from the supplier/customer in the hinterland. The foreland of the triptych is a port zone that is far away from the port and is the source or destination of the flow of goods that are coming to or leaving from the port [2]. In particular, the foreland of a port is to be understood as the land area lying on the seaside of the port, excluding the sea area itself. Sea carriers are the link between the foreland of the port and the port itself [3,4]. Port users are entities that operate in the port as part of the process in cargo transshipment from a given place of cargo shipment to a given destination place. Hence, port users are cargo carriers and shippers that utilize ports for freight transportation [5].

Port nautical accessibility refers to the ability of a port to service large vessels at any time. To adjust to the trade growth and offer economies of scale in a highly competitive market, many shipping companies have purchased larger ships. Such a structural change in size of vessels imposes operational challenges on ports. Crucial port investments are needed to accommodate such vessels and to meet the demand for shorter times of turnaround. Moreover, these ports that do not spend their expenditures for investment accordingly may lose their market shares. Therefore, these new requirements become a sine qua non condition for those ports that are willing to keep the pace of market changes and want to defend their competitiveness [6,7].

Seagoing vessels, in general, incur economies of vessel size at sea. Economies of vessel size at sea arise because ship costs in cargo transporting at sea do not grow proportionally to the increase in ship size. At sea, vessels exhibit economies of ship size, i.e., ship costs per tonne/TEU at sea decrease as ship size increases, e.g., [8–10]. Ports that can service larger ships while maintaining quick ship turnaround time (i.e., time differences between ships that are entering and leaving a port) will achieve an increase in the number of calls by larger ships and freight volumes in transshipment.

From a microeconomic point of view, an investment in a port's fixed assets and facilities normally causes an increase of transshipment for both total and per time unit as well as an improvement in quality of port services [11]. First, port investment causes transport-efficiency gains such as shorter service times and lower costs for port users (freight carriers) and economic benefits for port operators. Expansion of the port's capacity reduces the costs for the port users, which reduces the total generalized transportation costs. This affects the decision of the route choice by freight carriers in favor of the specific port, assuming that everything else stays unchanged [12].

The scope of port investment has an impact on the economic efficiency, which entails the following: (1) direct effects that are manifested in cost savings for port users and operators; (2) indirect effects that are passed on to other companies through a price mechanism; and (3) external effects that are independent of the price mechanism, e.g., traffic congestion and environmental pollution.

The good part is that port users demand efficient (i.e., cheap and fast) port services. Ocean carriers are one of the most important cargo carriers.

This manuscript investigates the impact of improved port nautical access on shipping operators and shippers. It aims at elaborating the direct effects for shipping operators and shippers resulting from port-improved maritime accessibility and capacity expansion. We quantified effects applying a generalized cost concept in maritime transport with the use of shipping operating costs, time cost, as well as cost economies of ship size.

Some aspects of port infrastructure that impact port users can implicitly be derived from studies concerning port competitiveness and port choice. Based on insights from the scientific literature (see e.g., [6]), the endowment of port infrastructure and nautical accessibility is mentioned among the key drivers of port competitiveness. A port is competitive if it possesses excellent hinterland and maritime access and offers superior connectivity to markets [13]. The problem of maritime accessibility and port competitiveness is further explored in [14–17].

The shipper chooses the port of destination. In fact, it happens through his (or his agent's) choice of carrier. Even when the carrier chooses the port, he only has a chance if he is himself chosen first [5,18,19]. The choice of destination port is dependent on the choice of supply chains that is made by shippers, shipper representatives, the shipping line, and others [20]. Travel time is considered by shippers as the most crucial factor of port choice. Consequently, thanks to such choice, shippers can minimize the costs of freight transportation incurred by travel time [18,21]. Shippers choose the port that is closest to the import or export cargo destination to keep their transportation costs low enough.

Malchow and Kanafani [22,23] indicate that a shipper, by choosing a carrier, implicitly chooses a port for a given shipment. They concluded that inland distance and ocean distance were the most crucial factors influencing port choice by carriers. Describing the determinants of maritime carriers' port choice, one of them is the consignment size, i.e., the amount of cargo to be transported by ships to and from the port. The larger the consignment size, the greater probability that a shipping operator will have its vessels call at a given port [5].

Veldman and Buckman [24] analyzed container port choice for both the continental and the overseas hinterland of West European container hub-ports. Such approach was later expanded to include the improvement of the accessibility of the port of Antwerp by deepening the Scheldt River [25]. Models have been developed for measuring competition between ports, and the most prominent explanatory variables for port choice are inland transport costs, ocean transport costs, port costs, and quality of port services [26].

Zondag [27] built a model of container port competition for Northwest Europe using a generalized cost function. The model allows to calculate port freight flows under different maritime sector scenarios. Such port competition-modelling integrates developments in trade by origin, destination, and cargo type, in ship sizes, maritime access, port capacity and efficiency, maritime access, and hinterland transport. The maritime model component consists of sea transport cost and times between port of origin and destination and uses time cost and distance cost values for six ship size categories.

Dekker [28] and Sanders [29] viewed port competition from the perspective of investments in port capacities. A dynamic port investment modelling addresses scale effects, congestion, competition, and development aspects of the transport network. Determination of demand for port services is essentially based on competition between alternative routes. In the analysis of economic impacts of port capacity investments in the port of Rotterdam [30], it is underlined that a capacity shortage will result in route changes of a part of the potential cargo flows through the port of Rotterdam to other ports, for instance, to Antwerp and Hamburg/Bremen. There is a constant threat that (parts of) cargo flows will shift to competing ports that offer more efficient (cheaper and/or faster) services. Substantial port investments are necessary to accommodate larger vessels and to meet the demand for shorter turnaround times. In most cases, delays in investment process by port authorities may result in a loss of market share [30].

Van Hassel et al. [31] developed a model that allows for estimating the impact of an increase in container vessel size on the generalized chain costs from a point of loading landside, through a port and maritime freight transport to another port and a point of unloading in the other hinterland. Scholars focused on the impact of larger container ships on the generalized costs of the sea–land transportation chain. The maritime component of the model consists of three main parts: a routing module, ship size module, and a cost module. In the maritime leg of the transportation chain, the model was applied to two different container routings (loops) with different ship sizes based on which generalized maritime transport costs were calculated. Jensen and Bergquist [32] calculated cost effects of several scenarios in intermodal chain by, among others, differing liner service direct traffic for a given container flow versus where the feeder traffic is replaced by direct traffic and vice versa. As for the maritime leg, they included in the cost function time-dependent vessel costs and distance-dependent vessel costs, costs of feeder and large deep-sea vessels, and changing vessel size and frequency.

From the review of related research, the relations between port investment, maritime costs, and trade flows have not been sufficiently addressed. There is a lack of research oriented on effects of port infrastructure capacity expansion on maritime trades, vessels, ports, and alternative routes, as well as maritime transport costs elements. When investigating the impact of improved nautical access on port users, the research should be conducted at disaggregated level referring to trade routes, freight types, vessel size, and costs of shipping and time.

This manuscript explores the impact of the improved port nautical access on port users, shipping operators, and shippers, and contributes to the existing literature in several ways.

First, it elaborates the direct economic link between the provision of port infrastructure and the performance of the shipping industry, the latter one being from the sea-leg perspective of the supply chain.

Second, the economic analysis resulting from port capacity expansion is distinguished for these effects coming from the spatial distribution of trades and shipping re-routings, and for those effects resulting from the increased vessel size (economies of scale).

Third, it quantifies the impact of port infrastructure improvements explicitly on port users, namely shipping operators and shippers, and thus creates sound grounds for port investment evaluation and policy decision making.

This manuscript contributes to the literature on problems of maritime logistics chain and relates to discussion on issues of energy consumption and savings in CO_2 emissions from ships [33–36], and sustainable developments of (circular) maritime logistics chains [37–42].

The research also gives insight into the broader perspective and global problems of sustainable management, as well as the development of supply chains in terms of dynamic capabilities, role of organizational learning and innovation, and supply chain management [43–45].

Our study elaborates on the Baltic and regional port of Szczecin (Poland). The port is a universal port and the cargo volume of 9 million tons per year qualifies it as a small and medium-sized Baltic seaport. The main deficiency of the port is its poor maritime accessibility. Recently, large-scale investments were made in the port of Szczecin, with the goal of improving nautical access to the port. The investments include deepening of a 67.35 km long waterway leading from the Baltic Sea to the port of Szczecin, as well as the expansion in port transshipment capacity. This will enable the port to handle larger vessels and will also increase the cargo handling capacity.

The effects are identified for maritime transport by comparing transport performance in two scenarios: with the investment and without the investment. Only the difference in-between two scenarios is considered, while the analysis addresses the flow of containers, dry bulk and cereals, changes in size of vessels, and shipping route alternatives vis-a-vis adjacent ports in the range. The economic impact of port investment concerns savings in generalized maritime transport cost, i.e., in shipping operating costs (energy consumption included), in the port-to-port transit time costs, and in environmental costs of maritime transport.

The research questions addressed by this study are as follows:

1. How does the improved port maritime excess affect foreland (maritime) transport performance?
2. What is the impact of improved port nautical excess on costs of sea freight transport?
3. What is the structure of port users cost efficiency gains?

To answer these questions, several net effects in maritime transport performance were identified, namely maritime transport distances and volumes of containers, dry bulk and cereals traded to and from port, changes in port competitiveness in the port range, and shipping route alternatives for trades and dispersion in sea distances. To capture economic effects, daily and unit dry bulk and container shipping cost, as well as values of time and marginal external costs, were revealed in freight sea transport. Next, as result of reduced maritime distance, savings in shipping and transit time costs for given cargo flows, as well as in externalities, were quantified. Finally, we estimated cost economies resulting from the increased size of container ship and dry bulk carriers, as well as account shipping operating cost savings for maritime freight trades.

The remainder of this paper is structured as follows. Section 2 presents the research concept and methodological framework. Section 3 refers to inputs and parameters of calculation. Section 4 measures cost savings as a result of reduced freight travel distance and increased vessels size and provides research results. Section 5 draws conclusions while Section 6 includes a discussion as well as further research needs.

2. Research Concept and Methodological Framework

We assume the shipping operators (carriers) and shippers seek to minimize the generalized maritime transport cost, which consists of shipping operating costs and transit time costs. Cost economies of ship size at sea, voyage distance covered by ships, as well as the transit time are crucial factors influencing sea freight transport costs. The development of generalized maritime transport cost with respect to sea distance, re-routings of freight flows, and changes in vessels size in view of the improved port maritime accessibility and transshipment capacity are analyzed. It distinguishes effects resulting from the reduced shipping distance and from the increased vessel size (economies of scale).

The main research problem is to identify the impact of the improved port maritime accessibility and transshipment capacity expansion on the sea freight transport performance and costs. We elaborate a scenario with the investment and a counterfactual scenario without the investment. In the latter, it defines what would happen in the absence of the investment. We compare freight sea transport performance in the port foreland that appears in the scenario: with deepening the fairway and transshipment capacity expansion (in the rest of this paper, this scenario is abbreviated to WI) and with the scenario without deepening the fairway and capacity expansion (in the rest of this paper, this scenario is abbreviated to W0). Finally, we only consider the net difference in transport performance in the scenarios: with the investment and without the investment. This approach is widely recognized in assessing the impacts of infrastructure projects and of large-scale transport projects (e.g., [46,47]).

In the research, a microeconomic approach is applied, which means the effects are measured directly in the transport system, named as internal or direct impacts of infrastructural improvements [48–50]. Port infrastructure investments either reduce distances and thereby travel time in sea freight shipping, and/or reduce congestion in port, and/or allow for accommodating larger ships. Either way, they make it possible to offer freight transportation services that are more efficient or more reliable, or both [50]. Direct benefits for shipping carriers and shippers are time related (time savings and reliability) and money related (ship's operating costs) [50]. Savings in operating and time costs in sea transport increase the surplus of consumers, shipping carriers, and shippers, and hence the welfare.

In the calculus of economic impact of investment, we used the concept of transport generalized cost, a notion that is widely recognized in transport economics (e.g., [31,51–54]), however, it means differing things according to research context and aims.

Limited to the main components and adopted to freight maritime transport, the generalized transport costs are the sum of the shipping operating costs (maritime carriers operating costs) and the value of transit time in port-to-port relations. In the cost function, the shipping cost and the monetary value of time are homogeneous and addable elements. The generalized sea freight transport costs GC may be defined as below [55]:

$$\mathrm{GC(D)} = \mathrm{P(D)} + \mathrm{H} \times \mathrm{T(D)},\ \text{where}: \frac{\partial \mathrm{P}}{\partial \mathrm{D}} > 0,\ \frac{\partial \mathrm{HT}}{\partial \mathrm{D}} > 0 \Rightarrow \frac{\partial \mathrm{GC}}{\partial \mathrm{D}} > 0,\ \text{and} \tag{1}$$

where:

GC(D)—generalized transport cost,
P(D)—shipping operating cost,
H—time cost per hour,
T(D)—port-to-port transit time.

Generalized transport cost in (1) is the sum of pecuniary costs that are related to the shipping operating cost (P) and time cost (HT), whereas the latter is the product of time cost per hour H and port-to-port transit time (T). It is assumed that P and T, and thereby also GC, are positively correlated to transport distance (D) measured in kilometers (km), while H is independent of the transport distance. We assume shippers and shipping operators choose the transport solutions that give the lowest generalized costs.

The economic effects are quantified using the GC_I and GC_0, being the generalised costs of freight sea transport, respectively, in scenario WI and W0. When the difference in the economic account takes negative values, i.e., $GC_I - GC_0 < 0$, it is interpreted as an advantage related to the reduction (savings) in generalized costs resulting from improved port infrastructure. The incremental approach was adopted to all transport performance and economic effects in the assessment.

This case study considers the small-and-medium-sized universal port of Szczecin located in the Baltic sea, whereas adjacent and competing ports located in the range consist of two major Polish ports of Gdynia and Gdańsk, and the German port of Rostock. Recently, large-scale investments were made in the port of Szczecin, with the goal of improving port maritime accessibility. This will enable the port to handle larger sea-going vessels and will also increase the cargo handling capacity. Effects of the investments are specified in Table 1.

Table 1. Effects of intervention in port of Szczecin.

Specification	Scenario without Investment W0	Scenario with Investment WI
Max. vessel draft (m)	9.15	11.1
Dry bulk carrier deadweight (tonnes)	20,000	40,087
Container ship capacity (TEU)	1000	1800
Transshipment capacity-grain (tonnes)	1,400,000	2,280,000
Transshipment capacity-containers (tonnes)	2,800,000	3,600,000
Transshipment capacity-dry bulk (coal, ore, other dry bulk) (tonnes)	2,900,000	4,600,000

Source: Authors' calculations.

The implementation of the project will enable handling a container vessel with a loading capacity of 1800 TEU and dry bulk carrier with a loading capacity of 40,000 tonnes. The annual throughput capacity of the port will increase in dry bulk, containers, and cereals, in total, by 3,380,000 tonnes.

Incremental calculus addresses volumes of freights (containers, dry bulk, and grain) traded to and from the port of Szczecin, changes in size of vessels, and the shipping route distance variation vis-a-vis adjacent ports in the range.

Inter-port competition in the range is analyzed straightforwardly, by comparing the following factors in the ports under study: (1) maximum vessel draft, which determines the size of vessel, and (2) the transshipment capacities for given cargo groups. Ship speed is constant regardless of the scenario and size of the ship. The size of sea-going vessels is classified according to the deadweight tonnage (abbr. DWT, or dwt), which is a measure of weight that a ship can carry. This is a total sum of cargo, fuel, both fresh water and ballast water, provisions, crew, and passengers expressed in tonnes. In the case of ships for the transport of containers, the size of such ships is measured by the number of equivalent 20-foot containers (TEUs) that they can transport at one time.

We established alternative sea routes and differences in maritime distance in the context of the port nautical access and capacity, which are sufficient to accommodate traffic and ships.

Only diverted traffic from other routes is considered, which means no generated (induced) traffic is assumed. Because of the difficulty in estimation, the problem of induced traffic is not incorporated in the standard freight demand forecasting procedure [56,57].

To capture economic effects, the long-term transshipment forecast in the port of Szczecin was elaborated to provide reasonable data input reflecting the expected development of good flow volumes over time designed for maritime trades. Also, daily and unit dry bulk and container shipping cost for a given size of vessels is estimated as well as values of time and marginal external costs in freight sea transport. With reference to alternative sea routes, incremental calculus (WI-W0) in maritime generalized transport costs in containers, grain, and dry bulk trades were made, as well as in external costs. Then, we calculated cost economies resulting from deploying larger container vessels and dry bulk carriers. We distinguished effects resulting from the reduced travel distance and from the increased vessel size (economies of scale), which resulted in savings of shipping operation and time costs also in maritime transport externalities.

The article draws a lot from the complex cost–benefit analysis performed by the Authors for the investment assessment in the port of Szczecin. Thus, both the developed port forecasts, values of inputs, and coefficients refer to year 2018 as a base year for calculations. Consequently, the period for which the analysis was carried out includes the waterway operation phase, which is 21 years (2023–2043). The social discount rate used in the analysis is 4.5%, with fixed prices from the account year and without considering inflation throughout the analysis period. In the calculation, unit values of economic benefits are presented in net terms (excluding VAT). The first year of operation of the deepened waterway is 2023, and from this year, economic benefits are calculated.

3. Inputs and Parameters

3.1. Forecasted Demand for Port Transhipment

Investment decisions require the development of long-term forecasts since ports generally have a long technical and economic lifetime, and investments made in port infrastructure have a long pay-back period [58].

Due to structural limitations related to its low transport accessibility, the port of Szczecin is facing barriers to its development and its transport importance has been diminishing. The crucial bottleneck in port of Szczecin accessibility is the depth of the Świnoujście–Szczecin waterway. The freight flow forecasting referred directly to trends and internal conditions at Szczecin's port, which is burdened with structural limitations of port growth and ignores relations with major ports. Following numerous studies on the dynamics of the development of multi-port systems, e.g., [59–66], it is generally acknowledged that the development of small and medium-size ports (SMPs) is determined by their relationships with major ports which, in turn, are based on the competition and complementarity of handling the growing demand for services in large ports. In our case, the port of Szczecin has a relationship with three other major Polish ports (Świnoujście, Gdańsk, and Gdynia). The method of forecasting the demand in port of Szczecin is therefore relative as it estimates the demand for transshipments in major ports and then uses the indices of the transshipment dynamics to develop forecasts of freight turnover in Szczecin port.

The regression equations for groups of cargo in major ports were estimated with the use of the long-term GDP forecasts of the Ministry of Development and Finance recommended for long-term forecasts in the Polish transport sector. However, the GDP forecasts did not consider the economic impact of the COVID-19 pandemic.

The projected volumes of cargo group throughput in major Polish seaports were converted into dynamics indices. The matrix of indices of demand dynamics for the transshipment of individual cargo groups, as established for Polish major ports, was used to predict demand for services of the port of Szczecin, whereas the starting year for the forecasts was 2018. Given the knowledge of average cargo groups throughput volumes recorded from 2007–2017 in the port of Szczecin and the chain indices of the forecasted increases in cargo throughput in major ports, the following recursive equation was used to produce cargo throughput forecasts for Szczecin's port:

$$C^*_{t,j} = C^*_{t-1,j} \cdot i_{\frac{t}{t}-1,j} + \overline{T}_{t-k-1,j} \tag{2}$$

where:

$C^*_{t,j}$—forecasts for j-th cargo group in time t,

$C^*_{t-1,j}$—forecasts for j-th cargo group in time $t-1$,

$i_{\frac{t}{t}-1,j}$—the annual chain indexes of dynamics of cargo throughput growth in j-th cargo group, and

$\overline{T}_{t-k-1,j}$—the average level of transit in j-th cargo group determined from k time periods.

The waterway depth does not prevent multi-purpose ships and tankers from calling at the port in Szczecin. According to the information provided by forwarders, the carriage of general cargo, chemical products, and oil products is carried out by ships with a maximum carrying capacity of 12,000 tons and a draught not exceeding 9.15 m. Regarding sea relations to and from the port of Szczecin, no increase in shipment size of these cargoes is expected in the future and, consequently, in the size of the ships. Therefore, for the purpose of forecasting, it was assumed that the transshipments of general cargo and oil will not change and will remain at their average throughput volumes recorded from 2007–2017.

Predicted cargo throughput volumes were additionally limited by the handling capacity of the port of Szczecin (Table 2).

Table 2. Throughput forecast in the port of Szczecin in WI scenario (growth rates).

Year	Coal	Iron Ore + Other Bulk	Grain	Container Cargo	Total
2023	0.0%	0.0%	0.0%	0.0%	0.0%
2028	3.1%	8.6%	22.1%	22.3%	9.4%
2033	6.2%	17.3%	39.0%	44.7%	17.9%
2038	9.1%	25.4%	40.2%	65.8%	23.2%
2043	12.1%	33.6%	40.3%	87.1%	28.3%

Source: Authors' calculations.

In the scenario without the investment, it is considered that the cargo traffic will remain constant around the average volumes of the previous period (2007–2017) for all types of cargo.

The growth indices vary among types of cargo. Container cargo is the most prospective group of freight in the port of Szczecin. It is estimated that due to the Świnoujście–Szczecin waterway deepening, container transshipment will increase by 87.1% in 2043 in comparison to 2023 (first year of waterway operation). Grain will be the second cargo type with a growth rate of +40.3% in the same period. Coal is the least increasing cargo type. It is estimated that coal will increase by 12.1% till 2043. Total cargo transshipment in the port of Szczecin will increase by 28.3% in the next 20 years.

Incremental throughput forecast is depicted in Table 3.

Table 3. Incremental (WI-W0) throughput forecast in the port of Szczecin (tonnes).

Year	Coal	Iron Ore + Other Bulk	Grain	Container Cargo	Total
2023	110,363	566,648	737,518	224,846	1,639,375
2028	170,390	874,852	1,164,006	412,719	2,621,966
2033	230,842	1,185,235	1,488,387	601,920	3,506,383
2038	287,846	1,477,918	1,512,801	780,332	4,058,897
2043	345,176	1,772,275	1,514,552	959,764	4,591,767

Source: Authors' calculations.

The overview of the projected total freight traffic in the port of Szczecin is depicted in Figure 1.

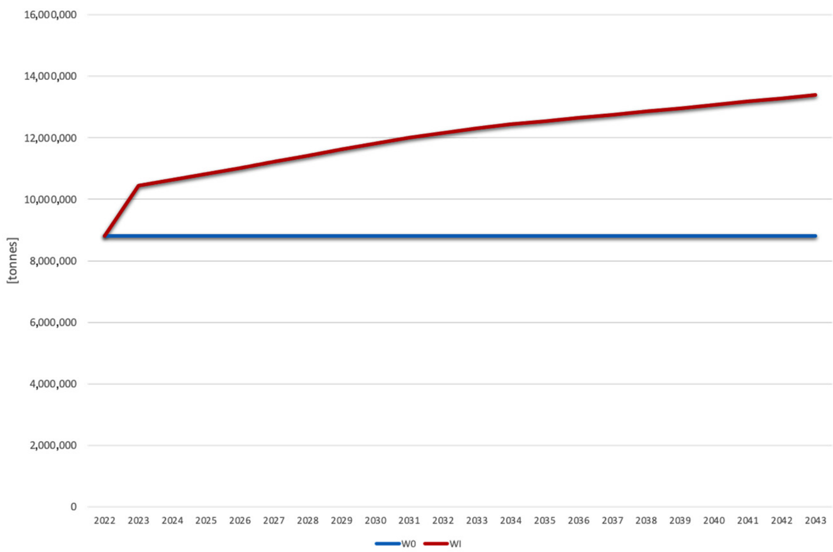

Figure 1. Forecasted cargo throughput in the port of Szczecin (tonnes). Source: Own elaboration.

The produced forecasts in the port of Szczecin anticipate a long-term increase in transshipment by +4.6 million tonnes. The forecasts indicate that the port in Szczecin will retain its universal character in the future, and a moderate increase in transshipment confirms that it will serve as a complementary port to the major Polish ports in the region.

3.2. Sea Distances of Freights Traded to and from Port of Szczecin

A detailed analysis of the volumes and distances of sea transport of dry bulk cargo, grain, and containers handled at the port of Szczecin was computed in Excel sheets, while the aggregated results are depicted in Table 4.

Table 4. Weighted average sea distances in containers, dry bulk, and grain traded to and from the port of Szczecin.

Year	Annual Weighted Average Sea Distance (km)		
	Container Cargo	**Dry Bulk Cargo**	**Grain**
2011	1037	1983	4085
2012	993	2433	2900
2013	1010	2262	4034
2014	1024	2700	4308
2015	997	2824	6925
2016	896	2386	9882
Weighted average sea distances	992	2429	5772

Source: own study, sea transport distances were determined based on http://www.sea-distances.org/ (accessed on 11 September 2020) and Polish Ports Handbook 2007, Maritime Economy and Industry Guide, LINK Szczecin 2007.

3.3. Port Competitiveness in the Range

When assessing port competitiveness in the range, maritime port accessibility transferred into the maximum draft of the ships, and transshipment capacity for containers, grain, and dry bulk freights were compared.

In the handling of containers, the closest to the port of Szczecin is the port of Gdynia, which has two terminals for handling containers. In the handling of bulk cargo (coal, ore, other bulk), the port of Gdańsk, which is the closest to the port of Szczecin, has an extensive capacity for transshipment of bulk cargo. In terms of the sea transport of grain, competing with the port of Szczecin are the ports of Rostock and Gdynia. Both ports have sufficient capacity for transshipment of grains. The navigation conditions for accommodating container ships, dry bulk carriers, and vessels with grain in the respective ports are presented in Table 5.

3.4. Shipping Route Alternatives and Dispersion of Sea Distances

The diversification of sea transport routes to the analyzed ports will occur in the Baltic Sea. The fairway to the Malmö port, located at the entry of sea-going vessels to the Baltic Sea, is used as a reference point. It is a common navigational position for ships serving the Baltic Sea freights. From this point on, the hypothetical distribution of sea transport is determined for the distinguished groups of cargo in the scenarios WI and W0 (Figure 2). In the W0 scenario, the forecasted volumes of freights will be directed to Rostock (for grain), Gdynia (for containers and grain), and Gdańsk (for dry bulk cargo). This is because the ports have sufficient conditions to handle larger ships and the capacity to reload cargo groups (point 3.3). In the WI scenario, the forecasted volumes of cargo are directed to the port of Szczecin. The differences in sea distances between the fairway to port in Malmö and the ports of Szczecin, Rostock, Gdynia, and Gdańsk are presented in Table 6.

Table 5. Maximum draft of vessels calling at the ports of Szczecin, Gdańsk, Rostock, and Gdynia.

Maximum Draft of Container Ships			
Scenario	Port of Szczecin Draft (m)	Port of Gdynia Draft (m)	
W0	9.15	Gdynia Container Terminal 11.0 m Baltic Container Terminal 12.7 m	
WI	11.1		
Maximum Draft of Dry Bulk Carriers			
	Port of Szczecin Draft (m)	Port of Gdańsk Draft (m)	
W0	9.15	Outer port 15.0 m Inner port 10.2 m	
WI	11.1		
Maximum Draft of Vessels with Grain			
	Port of Szczecin Draft (m)	Port of Rostock Draft (m)	Port of Gdynia Draft (m)
W0	9.15	Berths (no 13, 17 and 18) for grain handling 13.0 m	Baltic Grain Terminal 11.0 m
WI	11.1		

Source: Authors' calculations.

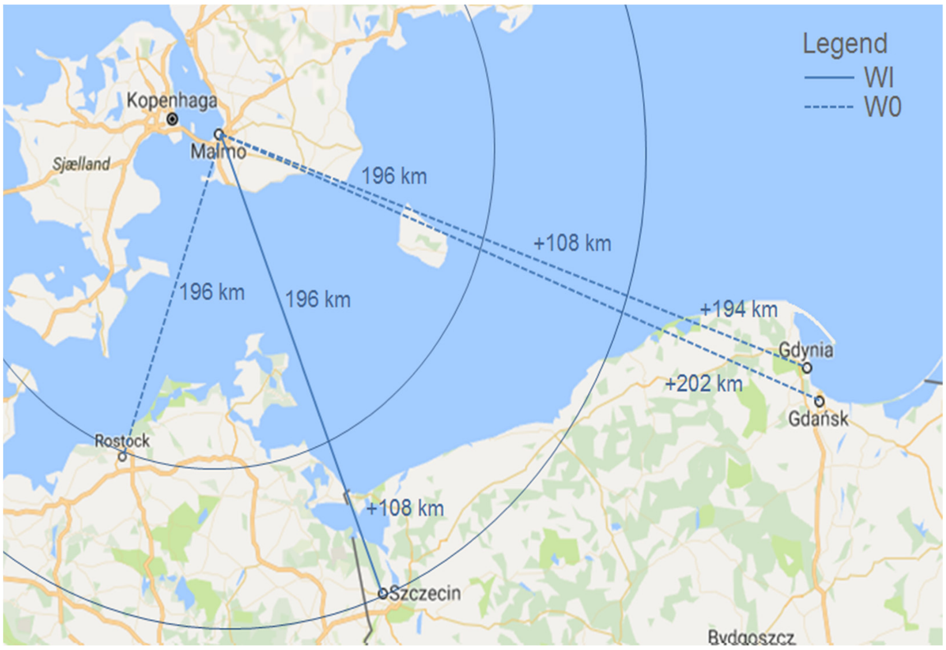

Figure 2. Scenario-based shipping route alternatives and sea distances for containers, dry bulk, and grain. Source: own study, distances are based on http://www.sea-distances.org (accessed on 11 September 2020).

Table 6. Differences in freight sea transport distance from the port of Malmö to ports of Gdynia, Gdańsk, Rostock, and Szczecin.

Port	Gdynia	Gdańsk	Rostock	Szczecin
Malmö (in nautical miles)	269	273	106	164
Malmö (in kilometers)	498	506	196	304
Difference in sea transport distance from Szczecin to other ports (in kilometers)	194	202	(−107)	0

Source: distances are based on http://www.sea-distances.org (accessed on 11 September 2020).

Cruising speeds of ships in both scenarios (WI, W0) are constant and amount to 25.93 km/h for a container ship, and 22.22 km/h for a bulk carrier. The transit time is defined as the number of sailing hours in relation to the reference point Malmö port to destination ports: Rostock, Szczecin, Gdynia and Gdańsk, respectively.

In the WI scenario, the increased flow of containers (WI-W0) will be redirected from the port of Gdynia to the port of Szczecin, and thus the distance of sea transport of containers will reduce by 194 km. The increased grain flow (WI-W0) will be re-routed from the ports in Rostock and Gdynia to the port of Szczecin. Compared to the port of Rostock, the voyage distance will increase by 107 km, while compared to the port of Gdynia, the distance will shorten by 194 km. Further, the increased flow of bulk cargo (WI-W0) will be redirected from the port of Gdańsk to the port of Szczecin, and thus the distance of sea bulk cargo transport will shorten by 202 km.

3.5. Daily and Unit Shipping Cost of Dry Bulk and Container Cargo

The transport costs of sea voyage in the port-to-port relation that are incurred by vessels include [67]:

- operating costs (administration, repairs and maintenance, staffing, stores and lubricants, and insurance),
- voyage expenses (fuel cost and port dues), and
- capital costs (interest and capital repayments).

The daily shipping cost (expressed in EUR/day) is calculated as follows:

$$\mathrm{DSC} = \mathrm{DOC} + \mathrm{DVC} + \mathrm{DCC}, \quad (3)$$

where:

DSC—the daily shipping cost,
DOC—the daily operating cost,
DVC—the daily voyage cost (fuel cost and port dues), and
DCC—the daily capital cost.

Components of the daily shipping costs of bulk carriers and container ships in the operation stage were taken from [68]. The authors presented the average daily shipping costs by selected groups of ships sizes. Thanks to the form of data presentation in the mentioned paper, a detailed structure of daily shipping costs is able to be presented. This is because the costs were calculated for the average vessel size in each vessel size group. The analysis was carried out for bulk carriers with guide deadweights of 25,000, 70,000, 85,000, and 155,000 dwt (Table 7), and for container ships with guide deadweights of 7308, 18,270, 66,991, 103,532, and 133,982 dwt (Table 8).

Marine fuel and capital costs are the main components of the shipping costs of a bulk carrier where capital costs mean instalments and interest on capital for financing the purchase of ships. Together, both cost categories account for nearly 80% of bulk carrier travel costs. Their share in total costs is independent of a ship's deadweight. The personnel costs related to ship staffing decrease in importance as the size of the vessel increases. Moreover, in relation to total cost, the personnel costs range from 5.4% for Handy size to 4.8% for large Capesize bulk carriers. It is important to note that shares of the other costs by type in total operating costs of bulk carriers are independent of ship size.

As with bulk carriers, marine fuel costs and capital costs with instalments and interest on the capital are a major component of container ship travel costs. Together, they amount from 68% to 74% of the total shipping costs, including small and large ships. In turn, unlike bulk carriers, there are significant changes in cost structure, as the size of a container ship increases. Namely, for small container ships, the share of fuel costs is 47% of total costs and as the size of ship gets larger, the share of fuel cost decreases down to 36.8%. This results in an increase of the share of capital costs from 21% up to 37% of the total shipping costs as the size of ship gets larger. The increase in size of the container ship leads to higher port costs and to lower ship management costs in the total costs of ship operation. Other types of container shipping costs such as insurance, repairs and overhauls, supplies, and oils, are independent of container ship size.

The daily shipping cost can be described by regression models. The power function is used for such models. Parameters are estimated due to ordinary least squares (OLS) estimator but for a linearized form. The daily shipping cost models with estimates can be written as follows: [69]:

- for dry bulk carrier

$$\hat{C}_i = \underset{(1.0785)}{1336.6} \times DWT_i^{\overset{0.2909}{(0.0068)}}, \tag{4}$$

where: 1336.6 is the estimate of the parameter of the cost model and 0.2909 is the average elasticity of the ship-day operation cost in relation to the *i*-th bulk carrier deadweight.

- for container ship

$$\hat{K}_i = \underset{(1.147)}{121.974} \times DWT_i^{\overset{0.565}{(0.013)}}, \tag{5}$$

where: 121.974 is parameter of the cost model and

- 0.565 is the average elasticity of the ship-day operation cost in relation to the *i*-th container ship deadweight.

Based on the established functional relationships, the daily cost of operation was calculated for the maximum load capacity (DWT) of the bulk carrier and container ship in the port of Szczecin in W0 and WI scenarios (Table 9).

Table 7. Daily shipping cost of dry bulk carrier (EUR/day) (2010).

Vessel Size	Handy Size	Panamax	Post Panamax	Capesize
Size range dwt	10,000–40,000	60,000–80,000	80,000–110,000	110,000–200,000
Guide dwt	25,000	70,000	85,000	155,000
Manning	1389	1847	1847	2069
Insurance	473	702	756	817
Repairs and maintenance	1107	1458	1656	1824
Stores and lube oil	374	511	557	611
Administration	947	1099	1160	1237
Capital repayments	3847	5837	6102	6898
Interest	3162	4798	5016	5671
Gross margin	1921	2763	2906	3251
Port	2100	2800	3000	3500
Fuel (tonne/day)	32.0	38.0	42.0	55.0
Fuel (EUR/day)	10,198	12,111	13,385	17,528
Speed (knots)	12.0	13.0	13.0	13.0
Full cargo weight (tonne)	European relations	Relations via Panama Canal	Relations via Suez Canal	Relations via Cape of Good Hope
	24,739	69,252	83,448	151,931
Total daily shipping cost (EUR/day)	25,519	33,927	36,387	43,406

Source: Data from [68].

Table 8. Daily operation cost of container ships in 2010 (EUR/day).

Vessel size (TEUs)	500–700	1000–2000	5000–6000	8000–9000	10,000–12,000
Average containership capacity (TEUs)	600	1500	5500	8500	11,000
Guide dwt	7308	18,270	66,991	103,532	133,982
Manning	1588	1588	2176	2313	2466
Insurance	313	443	931	1168	1336
Repairs and maintenance	802	977	2603	2786	3092
Stores and lube oil	351	580	1557	1847	2122
Administration	504	550	931	962	1008
Capital repayments	2189	4378	11,276	16,848	20,430
Interest	1799	3599	9269	13,850	16,794
Gross margin	1283	2059	4886	6762	8032
Port	1200	2500	5200	6800	8300
Fuel (tonne/day)	28.0	45.0	77.0	91.0	116.0
Fuel (EUR/day)	8924	14,341	24,540	29,002	36,969
Speed (knots)	14.0	14.0	18.0	18.0	18.0
Full cargo weight (tonne)	European relations	European relations	Relations via Panama Canal	Relations via Suez Canal	Relations via Cape of Good Hope
	7200	18,000	66,000	102,000	132,000
Total daily shipping cost (EUR/day)	18,952	31,015	63.370	82,337	100,547

Source: Data from [68].

Table 9. Dry bulk carrier and container ship daily shipping cost (2010).

Ship Type	DWT (W0)	Daily Shipping Cost EUR	DWT (WI)	Daily Shipping Cost EUR
Dry bulk carrier	20,000	23,833	40,087	29,175
Feeder container ship	TEU (W0)	24,907	TEU (WI)	34,726
	1000		1800	

Source: Authors' calculations.

Two crucial assumptions underpin the calculation of the unit shipping cost of bulk carriers and container ships per tonne-kilometer. These assumptions are as follows:

1. The ship capacity is fully used (in tonnes of cargo).
2. Sailing speed for a given ship size is constant; consequently, the travel distance that the ship can cover in a 24-h period is constant too (in km).

Therefore, the unit shipping cost (in EUR/tkm) is defined as:

$$USC = \frac{DSC\ (DOC + DVC + DCC)}{FCW\ \times\ DD} \quad (6)$$

where:

USC—the unit shipping costs,
DSC—the daily shipping cost,
DOC—the daily operating cost,
DVC—the daily voyage cost (fuel cost and port dues),
DCC—the daily capital cost,
FCW—the full cargo weight (tonne)/vessel,
DD—the maximum daily distance (km),

S—speed (km/h, constant), and
DD = S × 24 h.

It means when calculating economies of scale, the additional effect resulting from economies of distance is disregarded.

The unit cost of a tonne-kilometer for ships (Table 10) is calculated as follows:

- The maximum distance of a sea voyage that a vessel can cover in 24 h was established. The cruising speed of a vessel was in use. Sea knots were converted into kilometers per hour. Then, the daily shipping cost was divided by the maximum voyage distance per day to obtain the cost of operating the ship per kilometer.
- The 1 tonne-kilometer cost of ship travel was calculated by dividing the operating cost per 1 kilometer of a ship's voyage by its full cargo weight.
- The operating cost data for bulk carriers and container ships were obtained for 2010; the nominal GDP growth rate in 2010–2018 at 28.07% was used to update operating costs for 2018. Applying indexing gives plausible values of unit shipping costs, although some operating costs are quite volatile (e.g., fuel costs), while others tend to increase at an inflationary rate (e.g., crewing and administration costs).

Table 10. Dry bulk carrier and container ship unit shipping cost (EUR/tkm, 2018).

Dry Bulk Carrier		
	W0	**WI**
DWT	20,000	40,087
Daily shipping cost (EUR/day)	23,833	29,175
Maximum load coefficient	0.95	0.95
Full cargo weight (tonnes)	19,000	38,082
Cruising speed in knots (NM/h)	12	12
Speed converter knots/km	1.85	1.85
Cruising speed km/h	22.22	22.22
Maximum daily voyage distance (km/day)	533.38	533.38
Operating costs EUR/km	44.68	54.70
Operating cost EUR/tkm 2010	0.0024	0.0014
Operating cost EUR/tkm 2018	0.0029	0.0018
Container Ship		
	W0	**WI**
Vessel size (TEUs)	1000	1800
Daily shipping cost (EUR/day)	24,907	34,726
Maximum load per 1 TEU (tonnes)	10	10
Full cargo weight (tonnes)	10,000	18,000
Cruising speed in knots	14	14
Speed converter knots/km	1.85	1.85
Cruising speed km/h	25.93	25.93
Maximum daily voyage distance (km/day)	622.27	622.27
Operating cost EUR/km	40.03	55.81
Operating cost EUR/tkm 2010	0.0040	0.0031
Operating cost EUR/tkm 2018	0.0049	0.0038

Source: Authors' calculations.

Estimates of unit shipping cost of dry bulk carrier and container ship are applied in further investigation.

3.6. Value of Time (VOT) and External Cost Coefficients in Freight Sea Transport

The unit time values applied in the study were originally estimated for the Netherlands [70,71]. Survey data on freight users' actual and hypothetical (stated preferences) choices between alternatives was used to measure willingness-to-pay (WTP) for freight time savings. The savings consist of two components—the time costs of transport (carrier component of VOT) and time costs related to cargo (shipper component of VOT). In our calculations, the indexes for 2018 values of time for containerized and non-containerized shipments are respectively 0.102 EUR/ton-hour, and 0.114 EUR/ton-hour (CUPT 2019).

To calculate environmental externalities in freight sea transport, we used external costs coefficients calculated in 2011 for general cargo/bulk carrier and container ships using low Sulphur fuel [72].

Marginal environmental costs were indexed by the nominal GDP growth index for the EU 27 calculated for the period 2011–2018 and multiplied by the elasticity-to-GDP index of 0.8. The values of unit environmental costs were expressed in EUR for 2018. The calculations are shown in Table 11.

Table 11. Marginal environmental cost coefficients for freight sea transport (fuel technology—low Sulphur fuel).

Externality	Ship Type			
	General Cargo/Dry Bulk Carrier EUR/1000 tkm	General Cargo/Dry Bulk Carrier EUR/1000 tkm	Container Ship EUR/1000 tkm	Container Ship EUR/1000 tkm
	2011	2018	2011	2018
Air pollution	4.48	5.17	3.09	3.56
Climate change	0.21	0.24	0.40	0.46
Total	4.69	5.41	3.49	4.03

Source: Authors' calculations based on [72].

Used in research of the total marginal environmental cost, coefficients for dry bulk carrier and containership amounted, respectively, to 5.41 EUR/1000 tkm and 4.03 EUR/1000 tkm.

3.7. Estimates of Marine Fuel Consumption and CO_2 Emission

Tables 12 and 13 are used to estimate fuel consumption by ships with data retrieved from 2010, while the fuel technology in shipping, on average, does not change in 2018 and consequently does not reduce marine fuel consumption per ship on average, as assumed.

Table 12. Estimates of marine fuel consumption per container ship with a size of 1000 and 1800 TEU.

Container Ship		
Average capacity of container ship (TEU)	2000	5500
Fuel consumption (tonnes/day)	45	77
Scaling parameter a	0.00914	
Constant b	26.71429	
Container ship	W0 (1000 TEU)	WI (1800 TEU)
Fuel consumption (tonnes/day)	35.86	43.17
Fuel consumption (tonnes/kilometer)	0.058	0.069
Fuel consumption (tonnes/million tonne-kilometers)	5.762	3.854

Source: Authors' calculations based on Table 8.

Table 13. Estimates of marine fuel consumption per bulk carrier with sizes of 20,000 DWT and 40,087 DWT.

Bulk Carrier		
Average capacity of bulk carrier (DWT)	25,000	70,000
Fuel consumption (tonnes/day)	32	38
Scaling parameter a	0.00013	
Constant b	28.66667	
Bulk carrier	W0 (20,000 DWT)	WI (40,087 DWT)
Fuel consumption (tonnes/day)	31.33	34.01
Fuel consumption (tonnes/kilometer	0.059	0.064
Fuel consumption (tonnes/million tonne-kilometers)	3.092	1.674

Source: Authors' calculations based on Table 7.

Volumes of CO_2 emission per marine fuel tonne for dry bulk carrier and container ship are presented in Table 14.

Table 14. Volume of CO_2 emission per marine fuel tonne for dry bulk carrier and container ship.

Vessel Type	Type of Engine	CO_2 (kg/t)
Dry bulk carrier	low speed diesel engine	3200
Container ship	medium speed diesel engine	3200

Source: Colls and Tiwary 2009.

4. Measurements and Results

4.1. Cost Savings as Result of Reduced Freight Travel Distance

There are three main sources of savings identified in the research induced by improved access to the port, namely:

- externalities,
- time travel, and
- travel costs.

Savings in external transport costs resulting from shortening of the travel distance are calculated as follows:

$$\Delta E_t = \sum_{i=1}^{n} C_{ti} \cdot \Delta d_i \cdot e_{ti}, \quad (7)$$

where:

ΔE_t—reducing of externalities due to the shortening of the travel distance in time t,
C_{ti}—forecasts of i-th cargo category (containers, dry bulk cargo, and grain) in time t,
Δd_i—the reduction of freight travel distance for i-th cargo category (constant in time), and
e_{ti}—marginal environmental transport costs of air pollution and climate change for i-th cargo type in time t.

The subscript i that appears in Formula (7) requires more explanation. The subscript means the type of cargo in combination with an alternative destination of transport of this cargo. It means that i varies from 1 to 4, i.e., i = 1 means transport of containers to/from Szczecin instead of Gdynia; i = 2 means transport of grain to/from Szczecin instead of Rostock; i = 3 means transport of grain to/from Szczecin instead of Gdynia; and i = 4 means dry bulk cargo transport to/from Szczecin instead of Gdańsk.

Reducing freight travel distance causes, at the same time, a diminishing of time travel costs. Such savings are calculated as follows:

$$\Delta TTC_t = \sum_{i=1}^{n} C_{ti} \cdot \Delta T_i \cdot utc_t, \quad (8)$$

where:

ΔTTC_t—reducing of time travel costs due to the shortening of the travel time in time t,
C_{ti}—forecasts of i-th cargo category (containers, dry bulk cargo, and grain) in time t,
ΔT_i—the reduction of freight travel time for i-th cargo category (constant in time), and
utc_t—unit time costs of freight travel in time t.

Finally, reducing freight travel distance has an impact on freight transport cost that can be calculated in such a way:

$$\Delta FTC_t = \sum_{i=1}^{n} C_{ti} \cdot \Delta d_i \cdot uftc_i, \quad (9)$$

where:

ΔFTC_t—reducing freight travel costs due to the shortening of the travel distance in time t,
C_{ti}—forecasts of i-th cargo category (containers, dry bulk cargo, and grain) in time t,

Δd_i—the reduction of freight travel distance for i-th cargo category (constant in time), and $uftc_i$—unit freight travel costs for i-th cargo type.

Ultimately, the transport savings due to the shortening of the travel distance consist of the savings in externalities, savings in travel time, and savings in travel costs, which can be written as follows:

$$\Delta TSDS_t = \Delta E_t + \Delta TTC_t + \Delta FTC_t, \quad (10)$$

where:

$\Delta TSDS_t$—the transport savings due to the shortening of the travel distance in time t,
ΔE_t—reducing externalities due to the shortening of the travel distance in time t,
ΔTTC_t—reducing time travel costs due to the shortening of the travel time in time t, and
ΔFTC_t—reducing freight travel costs due to the shortening of the travel distance in time t.

Nominal total savings of shortening the travel distances amounted to EUR million 186.1 in the period of economic analysis, with externalities accounting for 49.2% of total savings, travel time savings 37.0% of total savings, and travel costs 13.8% of total savings.

4.2. Cost Savings as Result of Economies of Vessel Size

To calculate the cost savings associated with the transport of cargo by larger ships (economies of scale and economies of vessel size), we used average sea distances for dry bulk, grain, and containers weighted by volume in the port of Szczecin foreland and already computed for the WI and W0 size of ships unit operating costs for dry bulk carriers and container ships (Table 9).

Contrary to the savings caused by the shortening of the transport distance, which arose from the distance increments, the economies of scale occur along the entire freight travel distance. Hence, the determination of average travel distances was necessary (Table 3).

Savings in transport costs of containers and dry bulk carriers resulting from the increased size of the ship were calculated as follows:

$$\Delta ESS_t = \sum_{i=1}^{n} C_{ti} \cdot (D_i + \Delta d_i) \cdot uftc_i^{W0} - \sum_{i=1}^{n} C_{ti} \cdot D_i \cdot uftc_i^{WI}. \quad (11)$$

Transforming the above equation, we get

$$\Delta ESS_t = \sum_{i=1}^{n} C_{ti} \cdot D_i \cdot uftc_i^{W0} + \sum_{i=1}^{n} C_{ti} \cdot \Delta d_i \cdot uftc_i^{W0} - \sum_{i=1}^{n} C_{ti} \cdot D_i \cdot uftc_i^{WI}. \quad (12)$$

Finally, we get the economies of scale equation as follows:

$$\Delta ESS_t = C_{ti} \cdot D_i \cdot \sum_{i=1}^{n} \left(uftc_i^{W0} - uftc_i^{WI} \right) + \sum_{i=1}^{n} C_{ti} \cdot \Delta d_i \cdot uftc_i^{W0}, \quad (13)$$

where:

ΔESS_t—an increment of scale economies in time t,
C_{ti}—forecasts of i-th cargo category (containers, dry bulk cargo, and grain) in time t,
Δd_i—the reduction of freight travel distance for i-th cargo category (constant in time),
D_i—weighted average distance of freight travel to/from port of Szczecin,
$uftc_i^{W0}$—unit freight travel costs for i-th cargo type in W0 scenario, and
$uftc_i^{WI}$—unit freight travel costs for i-th cargo type in WI scenario.

The total nominal cost savings resulting from the operation of larger seagoing vessels accumulated for period of 2023–2043 will amount to EUR million 475.2.

4.3. Savings in Marine Fuel Consumption and in Emission of CO_2

The total marine fuel consumption for container ships and dry bulk carriers was determined by multiplying the unit fuel consumption for container ships with a capacity of 1000 TEU and 1800 TEU, and for bulk carriers with a carrying capacity of 20,000 tons and 40,087 DWT by the amount of sea transport ships performance (in ton-kilometers) as for the W0 scenario.

Fuel consumption in the W0 and WI scenario is the product of the transport performance in W0 (cargo volume according to the demand forecast in W0 x sea distance to the port of Szczecin) and fuel consumption per kilometer for ships of W0 and WI size.

The savings in CO_2 emissions were calculated by multiplying CO_2 emissions per tonne of fuel by the total fuel consumption of ships of sizes W0 and WI.

As a result of the port investment, the total savings in fuel consumption in the years 2023–2043 will amount to: 24,613 tonnes for container ships, and 554,948 tonnes for dry bulk carriers. Savings in CO_2 emissions in 2023–2043 will amount to: 78,760 tonnes for container ships, and 1,775,834 tonnes for dry bulk carriers. In total, CO_2 emissions will be reduced by 1,854,594 tonnes during the analysis period.

As investigated, induced by investment in the port of Szczecin, the total economic effects in the sea leg of the supply chain include costs savings resulting from the operation of larger sea-going vessels (economies of scale) and caused by the shortening of the transport distance. The calculated total and discounted (with a discount rate of 4.5%) economic effects induced by the investment are summarized in Table 15.

Table 15. Total and discounted economic effects induced by the port investment (EUR).

Economic Effects Induced by Port Investment		
Savings resulting from the shorter maritime travel distance in:	Discounted Value	Structure (%)
- external/environmental costs	57,240,487.10	15.0
- shipping operating costs	15,125,027.64	4.0
- costs of travel time	41,962,390.76	11.0
Savings in operating shipping costs resulting from the increased ship size (economies of scale)	266,918,647.06	70.0
Total	381,246,552.56	100.0

Source: Authors' calculations.

Effects of shortening the transport distance include savings in environmental costs, in travel time cost, and in operating cost, and constitute, respectively, 15.0%, 11.0%, and 4.0% of the total discounted economic effects. Economies of scale amount to 70% of the total discounted economic effects, where the bulk freight and grains have a major impact. This is plausible as bulk and cereals are mostly transshipped in Szczecin port and their key impact is evident.

5. Conclusions

The final beneficiaries of seaport infrastructure provision will be:

- shipping operators, who will benefit from the savings in operating costs resulting from shortening freight travel distance and, for most, from economies of vessel size, and in total, it accounts for 74% of the total effects the port investment;
- shippers, exporters, and importers—because of shorter sea freight travel and thus time cost savings, and these benefits account for 11,0% of the total benefits of the port investment; and
- the community—thanks to the decreased maritime transport-related environmental externalities as an effect of shorter sea freight travel, which amounts to 15% of port investment impact.

Total savings in operating and time costs also in externalities constitute the surplus of the consumer, and hence increase the welfare for the total value of EUR million 381.2.

6. Discussion

Improved maritime accessibility allows for accommodating larger ships in the port, and thus cost savings are technology sourced, i.e., related to increased sizes of vessels. At the same time, the number of ports adapted to handling large ships is growing in the region, which means that (1) more ports may be chosen and (2) more alternative routes are at disposal. Thus, cost savings are embedded in spatial distribution, because of trade re-routings and reduced voyage distance. Our study confirms that economies of scale predominate, and they are responsible for 70% of cost gains. Economies of shorter transport distance in the foreland account for 30% of cost savings. Also, cost economies of ship size at sea and voyage distance covered by ships are crucial factors influencing generalized costs in maritime transport.

There are several generalities that can be applied in further research, such as:

- the concept of generalized transport costs in sea freight shipping as well as the concept of a reference point to research re-routings of trades and dispersion in distances, as well as their consequences in transport performance and costs;
- models of daily operating cost estimates as a function of dry bulk carriers and container ship size; and
- revealed values of time and external cost coefficients in freight sea transport.

However, due to forecasting port demand, setting port range and competitiveness of adjacent ports, as well as spatial distribution of freight flows in foreland, there are context-wise and case study issues.

The limitations of the study result from some assumptions made. In the analysis of changes in the trade routings and in the freight, volume is carried out with constant maritime accessibility and capacity in the neighboring ports, also with unchanged efficiency of port transshipments and hinterland connections. Similarly, in the port of Szczecin it is assumed that the duration of stay of a large ship under reloading operations will not be extended, and the efficiency of transport to the hinterland will not change. We also assumed that the total incremental volumes of freights (WI-W0) would be fully taken over by larger ships from the first year the investment is operational. These assumptions are rather strong in the context of the long-term horizon the analysis is performed over.

Additionally, this study's limitations result from the prognostic data used. When forecasting port transshipment, we used a historical relationship with Polish GDP whilst, in the future, these relations may change with unknown magnitude and direction. Moreover, the Polish GDP forecast used is also questionable given the recent global Covid-19 pandemic. Furthermore, projected values of time in freight sea transport and cost of CO_2 emission can be the subject of the future unpredictable structural, social, and economic changes and shocks. Also, we were not able to account for the ships' fuel technology changes and the future results of the policy regulations aimed at reducing CO_2 emissions.

Therefore, the question of the elaborated forecasts' reliability and the projected economic effects as well as energy and CO_2 savings remain valid.

Further, we assumed the shipping operators (carriers) and shippers make port choices to minimize the generalized maritime transport cost. However, factors other than generalized cost play a role in the choice for a particular logistic chain and port as e.g., reliability and strategic decisions. Also historical, psychological, political, and personal factors can result in the routing of cargo flows that diverge from the cost-efficient solutions. Bounded rationality, inertia, and opportunistic behavior are among the behavioral factors that could lead to a deviation from the optimal solution [73].

Further research should focus on spatial and traffic flows interactions, for example, with the use of gravity models. General maritime transport costs and the maritime freights distances are the main inputs in the modelling. Also, there are challenging issues of forecasting port demand and port choice, for example, with the use of discrete choice models. It is important to research the impact of port capacity expansion on port authority, terminal operators, and hinterland operators. Lastly, refinement of models measuring competition between ports and multifaceted research aimed at energy savings and reducing environmental costs in the shipping industry, is also encouraged.

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