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SELECTED POLYNOMIAL IDENTIFICATION TECHNIQUES TO EVALUATE MARITIME TRANSPORT TRENDS AROUND COVID-19

Summary. The Covid-19 pandemic has drastically affected the transport sector, because of the restrictions introduced to limit the spread of the threat. They concerned primarily passenger traffic, but trade in goods also faced completely new challenges, related to increased consumption and the dynamic development of e-commerce on the one hand and restrictions related to the pandemic and sealing borders on the other. One of the most susceptible to fluctuations in international trade is the maritime economy, which has been analysed in this article. It was checked how the global threat affected sea traffic in terms of gross weight of goods handled in main ports. The aim of the study was to characterize the impact of the pandemic on sea transport depending on the type of ship and to evaluate the current state of sea transport in the context of the level shaped by forecasts based on observations from before the coronavirus pandemic. The authors' assumption was to check whether the rail transport market has already reached the level it could reach in the absence of the virus threat. The use of a polynomial function was proposed for the study. Time series containing observations up to the outbreak of the pandemic and forecasts based on them, as well as time series containing additional observations from the pandemic period were analysed. The study results

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obtained allowed to conclude how the global crisis caused by the Covid-19 pandemic affected the cargo traffic in the sea transport, expressed by the mass of goods transshipped in major ports, depending on the individual types of ships.

Keywords: sea transport, Covid-19 pandemic, cargo ships, polynomial function

1. INTRODUCTION

The Covid-19 pandemic has drastically affected the transport sector. It was one of the first branches of the economy on which a number of restrictions were imposed to limit the spread of the threat. Almost immediately after its outbreak, restrictions were introduced on passenger transport, both international and domestic [38, 25]. For air passenger transport, it was the biggest crisis in history [3]. Moreover, of all industries, the aviation sector turned out to be one of the most affected [34, 41]. The extraordinary drop in passenger numbers, due to the bans on flights in individual countries, has led to the suspension of most airlines. Operators had to stop their activities; airports were closed, and all private and commercial flights were suspended [40, 2]. Drops of several dozen percents were recorded (the largest decrease compared to the same period of the previous year was recorded in April and amounted to 87% [19]). According to IATA, the crisis resulting from the pandemic has cost aviation more than $200 billion [15]

A similar impact was recorded on the rail passenger transport market. Railway carriers recorded a significant decrease in volumes resulting from the introduced restrictions, but also a significant reduction in economic activity, due to the introduction of remote work and the transfer of business meetings to the network [5, 52, 53]. The global reduction in the demand for rail passengers was about 80% - 95% [45], which was also largely due to the change in the preferences of commuters, who began to choose individual means of transport, such as a private car, cycling or walking, replacing public transport in particular [16, 42]

In Europe, in 2020, the number of travellers decreased in individual countries by 26 to 65% compared to the previous year [12, 43]. Transport restrictions in the urban agglomeration, in turn, caused the number of visitors to public transport locations to drop by as much as 80% [36] (March 2020), and the number of public transport passengers worldwide fell by 50-90% [37]. Similarly, the pandemic has reduced maritime passenger transport, reducing the number of sailings by almost 45% [32]. Human activities in the oceans have been radically altered, especially in the context of passenger ferries and cruise ships. Cruise tourism has been partially or completely suspended, and port activities in terminals have been limited to a minimum to ensure the safety of the operating personnel [29, 8].

Changes in freight transport were not so significant. The pandemic became the reason for increased consumption and a dynamic shift towards e-business, which is why transport companies had to take action to maintain international mobility and provide services at the highest level while complying with security procedures [51, 23]. As a result, by the end of 2020, the global air cargo sector has decreased by only 8% [18]. Similarly, rail transport, which in 2020 recorded a decrease in transported weight by 5.6% (EU) [11]. Global road freight transport experienced a significant drop in the first lockdown period in 2020, but on an annualized basis, it fell by only 1% (EU) in terms of ton-kilometres (tkm) compared to 2019 [13].

One of the most vulnerable to fluctuations in the international trade is the maritime economy. Maritime transport is responsible for the transport of nearly 80% of the volume and 70% of the value of international trade in goods, including goods of key importance to the economy, such as food or fuel. It is responsible for 64% of the world's GDP [9, 1, 30]. Therefore, this article examines this branch of transport by checking how the global threat affected sea traffic expressed in terms of the gross weight of goods handled in main ports. Due to the fact that there are significant differences depending on the transported goods, various types of ships were analysed (ships intended for the transport of containers, for the transport of dry and liquid bulk cargo, gaseous cargo, and also adapted for the transport of rolling cargo and vehicles - Ro-Ro).

The aim of the study was to characterize the impact of the pandemic on sea transport depending on the type of ship and to evaluate the current state of sea transport in the context of the level shaped by forecasts based on observations from before the coronavirus pandemic. The authors' assumption was to check whether the rail transport market has already reached the level it could reach in the absence of the virus threat. It was proposed to use a polynomial function for the study, because in the examined time series, the transport weight did not meet the stationarity postulate. The degree of the polynomial was selected using the difference method and by analysing quadratic variations of differences, and then adding successive transformations of the time factor and using linearity tests of the models.

A time series containing observations up to the outbreak of the pandemic and a time series containing additional observations from the period of the pandemic were analysed. For each series, a trend was determined, which was described using a polynomial, and forecasts were additionally set for the time series until the outbreak of the pandemic. They were used to compare the current state of sea transport with the forecast based on observations that do not take into account the resulting threat. This allowed us to conclude to what extent the global crisis caused by the Covid-19 pandemic has already been overcome.

In addition, by analysing the degree of the polynomial, it was possible to draw conclusions on the significance of the impact of the pandemic on the freight traffic of sea transport. If the trend in the series was identified using a polynomial with a lower degree, it indicated in a certain way the resistance of a given series to external factors, the higher the degree of the polynomial, the more local extremes, and the lower the resistance to market fluctuations [31, 55].

The transport industry turned out to be one of the most vulnerable and affected industries during the pandemic. The obtained results of the study allowed us to conclude how the global crisis caused by the Covid-19 pandemic affected the cargo traffic in sea transport, expressed by the mass of goods transshipped in major ports, depending on the individual types of ships.

2. MATERIAL AND METHODS

The study presented was conducted using data from the European Statistical Office EUROSTAT. They concerned the gross weight of goods transhipped in major ports, first in general terms and then broken down by the type of cargo [10]. Individual types of ships, dedicated to transporting specific types of goods, were analysed. They were:

Liquid bulk goods, that are carried unpackaged and usually transported in ships, which are commonly referred to as tankers. The specificity of this transport concerns primarily the process of loading and unloading, which is more complicated than in the case of other types of cargo. Modern ships are loaded using discharge/articulated arm loading systems, which are usually found in the off- and onshore loading and off-loading facilities, while in offshore oil fields, crude oil can be refuelled directly from the drilling rig. Liquid bulk cargoes are generally classified as edible, inedible, hazardous and non-hazardous [26, 21]. Dangerous liquids include crude oil, LPG (liquid petroleum gas), LNG (liquid natural gas) and chemicals (chemicals). The liquids other than non-hazardous ones are, for example, vegetable oils, cooking oils, milk, juices and other liquids that do not pose a potential threat to the body and the environment [26, 21].

Dry bulk goods, most often uniform in composition, loaded directly into the cargo area of a ship, mainly refer to unprocessed materials intended for use in the global production process, most often those that must be kept dry throughout the transport period. In particular, most agricultural products, such as cereals, seeds, fodder, sugar, cocoa, and coffee, belong to this category, but there are also products from the construction industry or the mining industry (metal ores, cement, and coal). Such products account for about 38% of the total maritime trade [14, 50].

Large containers can house almost any types of goods; hence, we distinguish containers for the transport of dry cargo, refrigerated, open, flat rack, tank, high cube, and others, which are transported on the ships specially equipped with guides intended for transporting this type of cargo units. In this case, a large part of the cargo is carried on board. The growing level of trade in the world is conducive to the popularity of container ships, and currently the largest of them can transport over 20,000 TEUs [46, 47].

Ro-Ro ships (short for Roll-on/roll-off) are adapted to carry rolling loads and wheeled means of transport (passenger cars, trucks, and railway wagons) [20]. They are distinguished by ramps used for loading and unloading, built in the bow or stern of the ship (or placed on land), thanks to which manoeuvring operations are much easier than when using a crane.

The time series of the gross weight of goods transhipped in ports for each of the above-presented ships have been studied. For each of them, a trend was identified in the time series $\{\varepsilon_{t_i}\}_{1\leq i\leq n}$, where $p \in \mathbb{N}$, and N denotes a set of natural numbers. The trend is presented in the form of a polynomial:

$$\varepsilon_{\tau_i} = \beta_0 + \beta_1\tau_i + \cdots + \beta_k\tau_i^k + \epsilon_{\tau_i} \qquad (1)$$

where $\varepsilon_{\tau_i} \overset{def}{=} \varepsilon_{t_i}$ and $\tau_i = t_i - t_1$ for $1 \leq i \leq n$, while $\{\epsilon_i\}_{1\leq i\leq n}$ is a sequence of independent random variables with a normal distribution $N(0,\sigma^2)$. The problem of determining the trend in the series involves the selection of a polynomial (including the determination of the degree of the polynomial) that will most accurately reflect the tendencies occurring in the observed phenomenon [44, 46]. Typically, the differential method is used to determine the degree of a polynomial. The relationship (1) between the endogenous variable and predictors (transformations of variable τ) is linear. The article presents the method of polynomial selection using the differential method and the linearity test (Ramsey test).

Differential method

In the differential method, it is assumed that the time intervals between successive readings in the time series are constant, i.e., $\tau_i - \tau_{i-1} = const,\ i \in \mathbb{N}$ and that $\tau_i \overset{def}{=} i$. This method consists of the analysis of successive differences between the elements of the time series [4, 17, 22]. The difference operator $\vartriangle$ is defined as follows:

$$\vartriangle \varepsilon_i \quad = \quad \varepsilon_i - \varepsilon_{i-1} \quad for \quad i = 2,3,\dots, \qquad (2)$$

$$\vartriangle^p \varepsilon_i \quad = \quad \vartriangle(\vartriangle^{p-1}\varepsilon_i) = \vartriangle^{p-1}\varepsilon_i - \vartriangle^{p-1}\varepsilon_{i-1} \quad for \quad i = p+1, p+2, \dots \qquad (3)$$

For a differential operator of order $p \in \mathbb{N}$ of the form (2)-(3) the equality holds

$$\triangle^p \varepsilon_t = \sum_{j=0}^{k} C_p^j (-1)^j \varepsilon_{t-j} \quad for \quad t = k+1, k+2, \ldots \qquad (4)$$

where $C_p^j = \binom{p}{j} = \frac{p!}{j!(p-j)!}$, $0 \leq j \leq p$.

If in the analysed time series $\{\varepsilon_{t_i}\}_{1\leq i\leq n}$ of the form (1) the non-random component is a polynomial of degree k, then using $k+1$ times the differential operator $\triangle$, the non-random component of the series [4, 17 , 22] is being completely eliminated. The resulting series of differences $\{\triangle^{k+1} \varepsilon_t\}_{t\geq k+2}$ is a linear combination of the series of residues $\{\epsilon_t\}_{t\in\mathbb{N}}$. If $\{\epsilon_t\}_{t\in\mathbb{N}}$ in the equation (1) is a sequence of independent random variables with distribution $N(0,\sigma^2)$, then:

$$\begin{aligned} \triangle^{k+1} \varepsilon_t &= \sum_{j=0}^{k+1} C_{k+1}^j (-1)^j \epsilon_{t-j}, && (5) \\ E\, \triangle^{k+1} x_t &= 0, && (6) \\ D^2(\triangle^{k+1} \varepsilon_t) &= \sigma^2 C_{2(k+1)}^{k+1} && (7) \end{aligned}$$

Selection of a polynomial using the differential method

1. successively for $p = 1,2,\ldots$ the series of differences $\{\triangle^p \varepsilon_t\}_{t\geq p+1}$ and the mean values are determined:

   $$\hat{m}_p = \frac{1}{n-p} \sum_{t=p+1}^{n} \triangle^k \varepsilon_t,$$

   and squared variations of the differences:

   $$\hat{\sigma}_p^2 = \frac{\sum_{t=p+1}^{n} (\triangle^k \varepsilon_t)^2}{(n-p) C_{2p}^p};$$

2. based on the analysis and evaluation of elements $\hat{m}_k$ and $\hat{\sigma}_p^2$, according to (6) and (7) [17, 22], we determine the moment p^* from which the mean values of the differences $\hat{m}_p$ are close to zero, and the elements $\hat{\sigma}_p^2$ begin to stabilize. The element p^* defines the degree of the polynomial overstated by one. This means that the deterministic part of the series $\{\varepsilon_i\}_{1\leq i\leq n}$ should be approximated by a polynomial of degree $k = p^* - 1$;
3. we identify the trend in the series $\{\varepsilon_{t_i}\}_{1\leq i\leq n}$ using a polynomial of k degree;
4. we use stepwise regression to determine the significant predictors in the model (1).

Ramsey test (RESET test)

The linearity of the model (1) was checked using the Ramsey test [35, 24] of the following form:

$$Y = X\beta + \epsilon \qquad (8)$$

where

$$X=\begin{bmatrix}1 & \tau_1 & \dots & \tau_1^k\\ 1 & \tau_2 & \dots & \tau_2^k\\ \vdots & \vdots & & \vdots\\ 1 & \tau_n & \dots & \tau_n^k\end{bmatrix},\quad Y=\begin{bmatrix}\varepsilon_{\tau_1}\\ \varepsilon_{\tau_2}\\ \vdots\\ \varepsilon_{\tau_n}\end{bmatrix},\quad \beta=\begin{bmatrix}\beta_0\\ \beta_1\\ \vdots\\ \beta_k\end{bmatrix}$$

At the significance level α $(0<\alpha<1)$ we construct a working hypothesis
H_0: the relationship between the dependent variable and the predictors in the model (8) is linear
and an alternative hypothesis
H_1: the relationship between the dependent variable and the predictors is not linear.

The Ramsey test [35, 49] consists of adding to the set of independent variables (successive regressors) in the form of powers, e.g., predicted values of an exogenous variable, independent variables or principal components.

A restricted model (8) is considered, in which, using the Least Squares Method [39, 48], estimators of unknown parameters $\hat{\beta}=(X^TX)^{-1}X^TY$, fitted values of the dependent variable $\hat{Y}=X\hat{\beta}$ and sequence of residuals $\varepsilon=Y-\hat{Y}$ are determined.

Then the extended (unrestricted) model is analysed

$$Y=[X,Z]\begin{bmatrix}\theta\\ \gamma\end{bmatrix}+\tilde{\varepsilon}, \qquad (9)$$

where the matrix $Z\in\mathbb{R}^{n\times(m-k)}$, $k<<m$ is defined as follows:

$$Z=\begin{bmatrix}\tau_1^{k+1} & \tau_1^{k+2} & \dots & \tau_1^m\\ \tau_2^{k+1} & \tau_2^{k+2} & \dots & \tau_2^m\\ \vdots & \vdots & & \vdots\\ \tau_n^{k+1} & \tau_n^{k+2} & \dots & \tau_n^m\end{bmatrix}.$$

Using the Least Squares Method, the estimators $\hat{\theta}$ and $\hat{\gamma}$ for model (9) are determined as

$$\begin{bmatrix}\hat{\theta}\\ \hat{\gamma}\end{bmatrix}=\left(\begin{bmatrix}X^T\\ Z^T\end{bmatrix}[X,Z]\right)^{-1}\begin{bmatrix}X^T\\ Z^T\end{bmatrix}Y$$

and a sequence of residuals

$$\tilde{\varepsilon}=Y-[X,Z]\begin{bmatrix}\hat{\theta}\\ \hat{\gamma}\end{bmatrix}$$

The test statistic of the Ramsey test [35] has the following form:

$$\phi=\frac{\|\varepsilon\|^2-\|\tilde{\varepsilon}\|^2}{\|\tilde{\varepsilon}\|^2}\frac{n-m}{m-k} \qquad (10)$$

and holds a Fischer–Snedecor distribution with $(m-k, n-m)$ degrees of freedom. Test probability $p.val = 2\min\left(F_{(m-k,n-m)}(\phi), 1 - F_{(m-k,n-m)}(\phi)\right)$, where $F_{(m-k,n-m)}(\phi)$ is the Fischer–Snedecor distribution with $(m-k, n-m)$ degrees of freedom.

Selection of a polynomial using the Ramsey test

1. for equation (1) we assume $k = 1$;
2. for model (8) we use the Ramsey test;
3. we estimate $p.val$;
4. if $p.val < 0.05$ and $k \leq m$ then we assume $k = k + 1$ and go back to point 2; otherwise, we go to the next point;
5. we identify the trend in the series $\{\varepsilon_{t_i}\}_{1\leq i\leq n}$ using a polynomial of k degree;
6. we use stepwise regression to determine the significant predictors in the model (1).

5. IDENTIFYING TREND FOR SEA TRANSPORT

Sea Transport in total

First, the sea transport as a whole was analysed, without division into specific types of ships. The volume of goods in the analysed years is presented in Fig. 1. There is a clear (black line) change in the development trend caused by the outbreak of the Covid-19 pandemic.

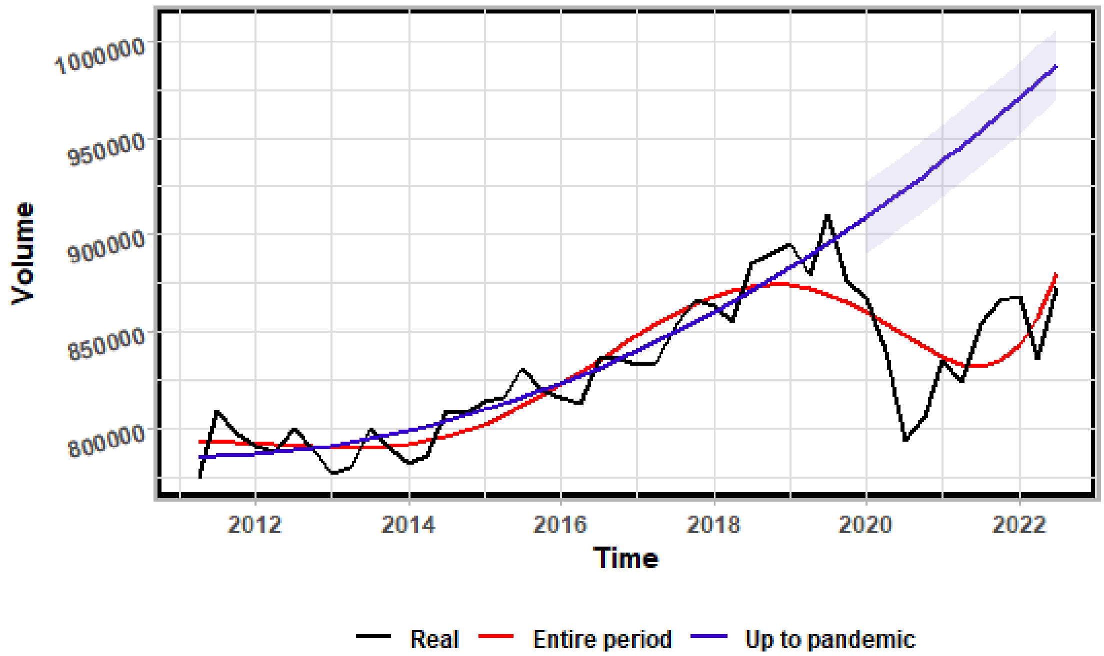

Fig. 1. Total sea transport in 2012-2022 (empirical data and model)

The identification was prepared based on the observations until the outbreak of the pandemic according to the model, which parameters are presented in Tab. 1 is marked in blue. The coefficient of determination was 0.911. Additionally, Tab. 1 contains the values of the estimators of the structural parameters of the model (1), standard deviations, values of the $\boldsymbol{t}$-test statistics and test probabilities regarding the lack of significance of the structural parameters [49, 39, 48]. At the significance level $\boldsymbol{\alpha = 0.05}$ we find that the intercept $\boldsymbol{\beta_0}$ and the coefficient $\boldsymbol{\beta_2}$ are significantly different from zero. The value of the Ramsey test statistic (10) is 1.9879 and the test probability $\boldsymbol{p.val = 0.09237}$, so there is no reason to reject the hypothesis about the trend in the time series is 2nd degree polynomial. On this basis, a forecast was additionally determined. There is a clear growing trend and dynamic development of sea shipments.

Tab. 1
Structural parameters for the trend matched to the pre-pandemic period – sea transport in total

	Estimate	Std. Error	t value	Pr(>|t|)
β_0	785171.20	2954.932	265.716	0
β_2	95.69	5.208	18.375	0

The identification made on the basis of observations during the entire analysed period is marked in red. The difference between the proposed forecast and the actual level is significant. Tab. 2 presents the structural parameters of the model for the entire period, standard deviations, $\boldsymbol{t}$-test statistics and test probabilities for these parameters. At the significance level $\boldsymbol{\alpha = 0.05}$ we conclude that the coefficients $\boldsymbol{\beta_0}$, $\boldsymbol{\beta_4}$, $\boldsymbol{\beta_5}$, $\boldsymbol{\beta_6}$ are significantly different from zero. The best fit was obtained for the sixth-degree polynomial. The coefficient of determination was 0.774. The value of the Ramsey statistic is 1.9121 and the test probability $\boldsymbol{p.val = 0.09765}$, so there is no reason to reject the trend hypothesis of 6-degree polynomial. A high degree polynomial shows significant fluctuations and low resistance of the series to external factors and market fluctuations.

Tab. 2
Structural parameters for the trend matched to the entire period – sea transport in total

	Estimate	Std. Error	t value	Pr(>|t|)
β_0	793071.547	6346.245	124.967	0.000
β_3	-22.211	11.309	-1.964	0.056
β_4	2.776	0.947	2.932	0.005
β_5	-0.093	0.027	-3.504	0.001
β_6	0.001	0.000	3.848	0.000

In the next stage of the study, sea shipments were analysed depending on the type of ship. This is justified by the varying demand for goods during the pandemic. While the demand for necessities and medical products increased sharply, the construction industry, for example, had a significant stagnation, which justifies the analysis of ships dedicated to individual goods.

Liquid bulk goods

Ships transporting liquid goods present characteristics similar to those of the entire transport, which is visible in Fig. 2.

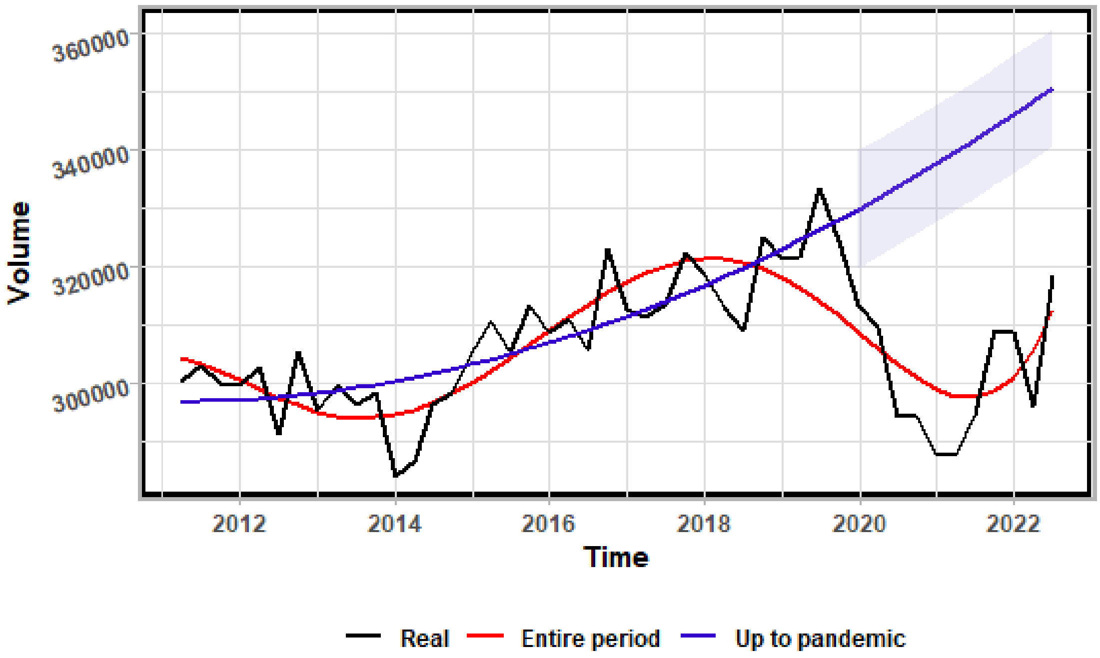

Fig. 2. Sea transport of liquid goods in 2012-2022 (empirical data and model)

The forecast prepared according to the model for observations until the outbreak of the pandemic shows a similar dynamic growth. The coefficient of determination of this model was 0.7105 and the values of the estimators, standard deviations, $\boldsymbol{t}$-test statistics and test probabilities are presented in Tab. 3. At the significance level $\boldsymbol{\alpha = 0.05}$ we find that the coefficients $\boldsymbol{\beta_0, \beta_2}$ are significantly different from zero. The value of the Ramsey statistic is 1.5984 and the test probability $\boldsymbol{p.val = 0.1777}$, so there is no reason to reject the hypothesis about the trend is 2nd degree polynomial.

Tab. 3
Structural parameters for the trend matched to the pre-pandemic period – liquid bulk goods

	Estimate	Std. Error	t value	Pr(>|t|)
β_0	296748.034	1608.377	184.502	0
β_2	25.506	2.835	8.998	0

The trend for the entire period was identified using a polynomial of 5 degree, which shows a significant sensitivity to external perturbations. The values of the structural parameter estimators of this model, standard deviations, $\boldsymbol{t}$-test statistics and test probabilities for these parameters are presented in Tab. 4. At the significance level $\boldsymbol{\alpha = 0.05}$ we conclude that the coefficients $\boldsymbol{\beta_0, \beta_2, \beta_3, \beta_4, \beta_5}$ are significantly different from zero. The coefficient of determination was 0.6185, the value of the Ramsey statistic is 1.6603, while the test probability $\boldsymbol{p.val = 0.1327}$, so there is no reason to reject the hypothesis regarding the trend in the form of a polynomial of 5 degree.

Tab. 4
Structural parameters for the trend matched to the entire period – liquid bulk goods

	Estimate	Std. Error	t value	Pr(>|t|)
β_0	304750.307	3460.161	88.074	0
β_2	-413.234	98.235	-4.207	0
β_3	42.933	8.528	5.035	0
β_4	-1.358	0.252	-5.388	0
β_5	0.014	0.002	5.491	0

The decrease in sea transport of liquid goods visible in the chart results from the decrease in global demand, which was recorded primarily in relation to all types of fuels, especially jet aviation fuels, due to the almost complete stoppage of air traffic. Demand for liquid petroleum gas (LPG) fell sharply and slightly less than the demand for petrol [7].

Dry bulk goods

The transport of bulk goods shows a different dependency. Of course, the changes in this area too, caused by the pandemic, were clear, and there was a sharp decrease (Fig. 3), but the growth dynamics in this case and its forecast, determined based on the observations until the outbreak of the pandemic, was not so significant and is linear.

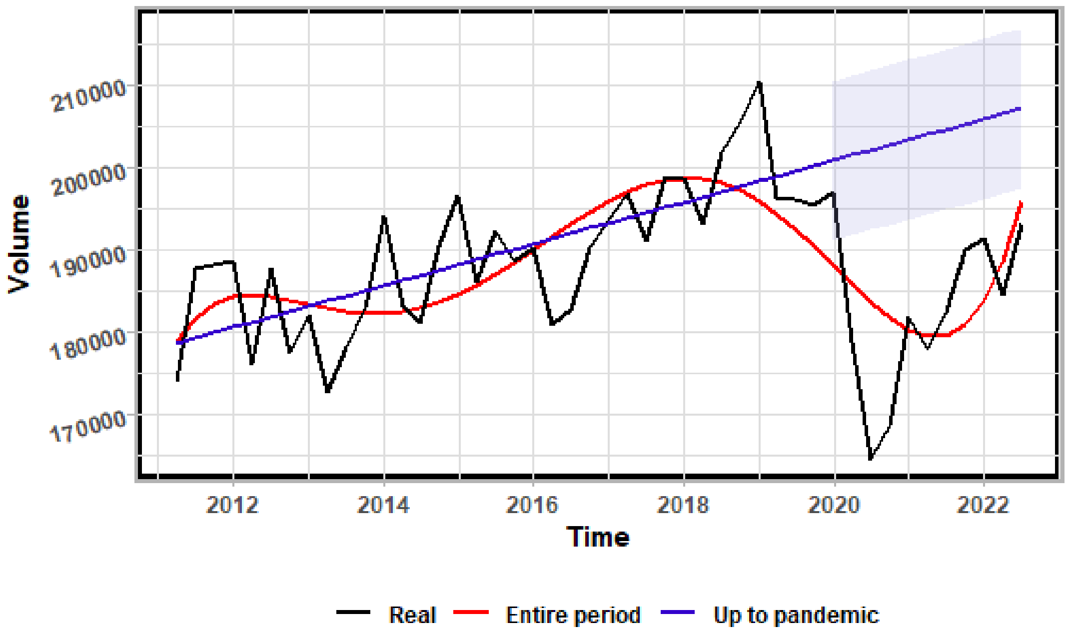

Fig. 3. Sea transport of bulk materials in 2012-2022 (empirical data and model)

The values of linear model estimators, standard deviations $\boldsymbol{t}$-test statistics and test probabilities are presented in Tab. 5. At the significance level $\boldsymbol{\alpha = 0.05}$ we determine that the coefficients $\boldsymbol{\beta_0, \beta_1}$ are significantly different from zero.

Tab. 5
Structural parameters for the trend matched to the pre-pandemic period – dry bulk goods

	Estimate	Std. Error	t value	Pr(>|t|)
β_0	178073.393	2095.727	84.970	0
β_1	631.454	101.538	6.219	0

The determination coefficient of the linear model was 0.5396. The value of the Ramsey statistic is 1.1473, while the test probability $p.val = 0.3542$, so there is no reason to reject the linear trend hypothesis.

In this case, the recovery of the market after the pandemic will take place faster, as shown by the model determined for the entire period. The structural parameters of the model, standard deviations, t-test statistics and test probabilities are presented in Tab. 6. At the significance level $\alpha = 0.05$ we conclude that the coefficients $\beta_0, \beta_3, \beta_4, \beta_5$ are significantly different from zero. The coefficient of determination was 0.4498. The value of the Ramsey statistic is 1.3297, while the test probability $p.val = 0.2643$, so there is no reason to reject the trend hypothesis of 5-degree polynomial.

Tab. 6
Structural parameters for the trend matched to the entire period – dry bulk goods

	Estimate	Std. Error	t value	Pr(>|t|)
β_0	174854.615	8055.985	21.705	0.000
β_1	4899.805	3331.416	1.471	0.149
β_2	-844.328	427.630	-1.974	0.055
β_3	57.105	22.788	2.506	0.016
β_4	-1.550	0.532	-2.912	0.006
β_5	0.014	0.005	3.191	0.003

This is due to the fact that a significant part of bulk sea goods are cereals, and the outbreak of the COVID-19 pandemic slightly disrupted their production, as it is weather conditions that are an important factor in this topic [54]. As a result of the pandemic, an increased demand for cereals could be observed resulting from increased purchases by states out of concern for food security. This was also facilitated by the fear caused by the introduction of the lockdown, causing the society to accumulate stocks, including food produced from cereals [54]. Hence, the rapid recovery of this sector.

Container transport

The COVID-19 pandemic also affected maritime container transport, which resulted mainly from the destabilization of the container trade management caused by the stoppage of some economies of the world (Fig. 4).

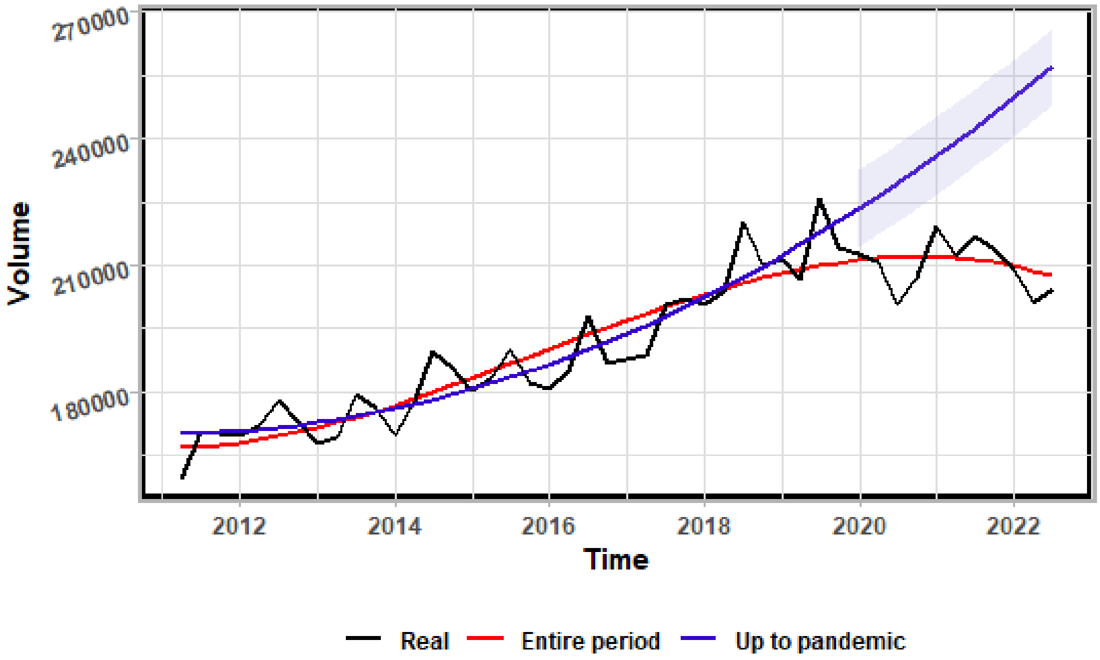

Fig. 4. Sea transport of container ships in 2012 -2022 (empirical data and model)

The values of structural parameters of the polynomial trend for the pre-pandemic period, standard deviations t-test statistics and test probabilities are presented in Tab. 7. At the significance level $\alpha = 0.05$ we conclude that the coefficients β_0, β_2 are significantly different from zero. The coefficient of determination was 0.8856, the value of the Ramsey statistic is 0.83441, and the test probability $p.val = 0.5817$, so there is no reason to reject the hypothesis regarding the trend in the form of a polynomial of 2 degree.

Tab. 7

Structural parameters for the trend matched to the pre-pandemic period – large containers

	Estimate	Std. Error	t value	Pr(>|t|)
β_0	170145.290	1458.753	116.637	0
β_2	41.091	2.571	15.984	0

However, Tab. 8 presents the values of structural parameters for the trend determined for the entire period, standard deviations of parameters t-test statistics and test probabilities. At the significance level $\alpha = 0.05$ we find that the coefficients $\beta_0, \beta_2, \beta_3$ are significantly different from zero. The coefficient of determination was 0.8803, the value of the Ramsey statistic is 1.6144, and the test probability $p.val = 0.1404$, so there is no reason to reject the hypothesis of a trend in the form of a polynomial of 3 degree.

Tab. 8

Structural parameters for the trend matched to the whole period – large containers

	Estimate	Std. Error	t value	Pr(>|t|)
β_0	166668.608	1864.480	89.391	0
β_2	88.765	8.600	10.322	0
β_3	-1.510	0.194	-7.781	0

In the case of container ships, in particular, the first months of the pandemic brought a reduction in the volume of transport and cancellations of cruises, but this was a short-term state [6]. Although in the most difficult period (February 2020), port container turnover fell almost to the level from 8 years ago, these were temporary phenomena. There was a quick revival, and the upward trend is still observed today [6]. This was due to the fact that the earlier (before the pandemic) growth in the container industry was strong enough to survive the effects of the crisis, and the reconstruction was supported by ongoing containerization and the relocation of production to Asia [28, 44].

Ro-Ro ships

Temporary disruptions in the sea transport of transport means resulted primarily from disruptions in the production of vehicles and the closing of showrooms, hence the short-term decline, which was quickly rebuilt (Fig. 5). This was also favoured by the growing popularity of ecological vehicles.

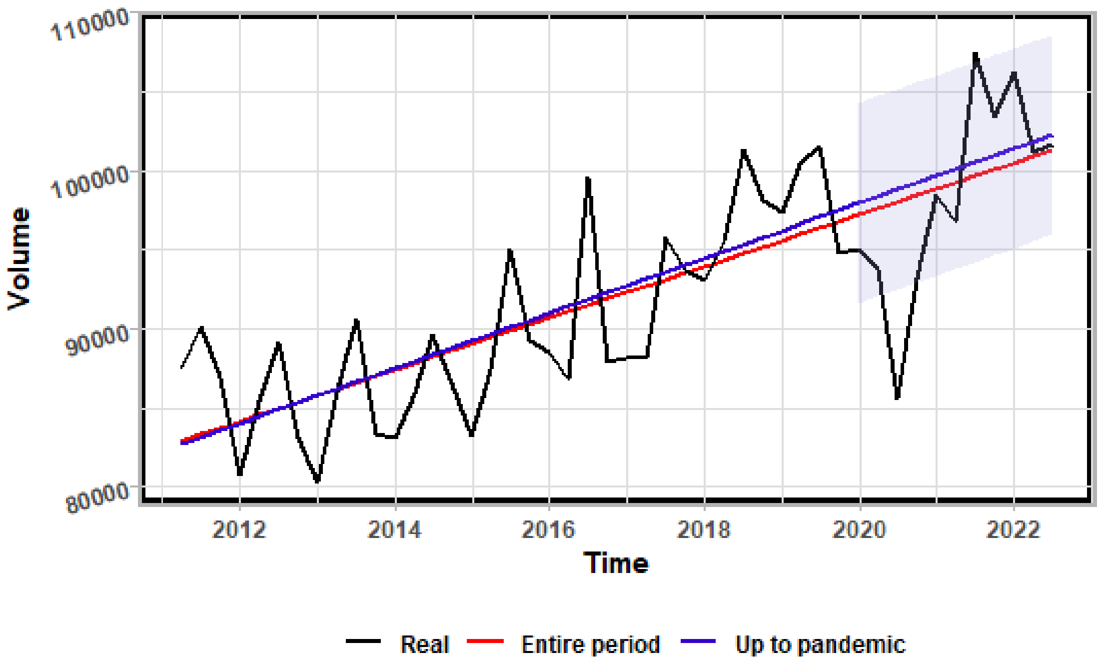

Fig. 5. Ro-Ro ships sea transport in 2012-2022 (empirical data and model)

Both the forecast according to the linear model for observations before the pandemic and the trend determined according to the linear model for the data from the entire period are very similar. The values of structural parameters for the linear model before the pandemic and for the model determined based on the data from the entire period, standard deviations of parameters $\boldsymbol{t}$-test statistics and test probabilities are presented in Tables 9 and 10, respectively. At the significance level $\boldsymbol{\alpha = 0.05}$ we find that the coefficients $\boldsymbol{\beta_0, \beta_1}$ are significantly different from zero for each of the models.

Tab. 9

Structural parameters for the trend matched to pre-pandemic period – Ro-Ro ships

	Estimate	Std. Error	t value	Pr(>|t|)
β_0	82280.861	1366.906	60.195	0
β_1	434.539	66.227	6.561	0

Tab. 10

Structural parameters for the trend matched to the whole period – Ro-Ro ships

	Estimate	Std. Error	t value	Pr(>|t|)
β_0	82499.901	1305.034	63.217	0
β_1	408.406	48.351	8.447	0

The determination coefficient for the pre-pandemic model was 0.5661, while for the entire period it was 0.6185. The value of the Ramsey statistic for the pre-pandemic model is 2.6928, while for the model from the entire period it is 1.6972. The test probability for the pre-pandemic model is 0.05054, while for the entire period it is 0.1697. Thus, at the significance level $\alpha = 0.05$ there is no reason to reject the linear trend hypothesis for each of the models, although in the case of the pre-pandemic model, $p.val$ slightly exceeds the significance level.

The restrictions related to the pandemic had an impact on the transport of vehicles resulting from the closure of production plants and points of sale, and the interruption of supply chains. However, short-term shortages in supplies and the limited availability of new cars affected the appetite of consumers, further intensified by their resignation from public transport due to fears of being infected and switching to private cars [33].

6. CONCLUSION

The transport industry, including maritime transport, has been clearly affected by the pandemic. For a short period of time, sea transport almost came to a standstill. However, the situation began to normalize quite quickly. The demand for sea transport was so great that - in parallel with the limited space on ships - it caused a rapid and significant increase in freight rates. The dynamics of changes in the freight price in the 3rd and 4th quarter of 2020 sometimes reached 10% - 15% of the freight price from the previous week, which ultimately resulted in a change of about 350% in the second half of 2020 compared to the levels from the beginning of July [27].

As it is shown in this study, global maritime freight traffic, expressed by the mass of goods transshipped in major ports, has in most cases not yet recovered to the level predicted on the basis of pre-pandemic data. However, the impact of the epidemiological situation on particular types of ships was very heterogeneous. The greatest fluctuations and low resistance of the series to external factors and market fluctuations concerned ships carrying liquid and dry goods. The polynomials determined were up to the fifth degree. This is due to the fact that especially fuels, as well as food and construction products, are very sensitive to the global economic situation. The transport of means transport turned out to be less sensitive - here the relation in time is practically linear and the impact of the pandemic on the trend line is negligible. Similarly, container ship traffic is more resilient to change. The security here is the ability to change the load, which can largely be adapted to the current needs of the market. During the pandemic, these were, for example, mainly hygiene items such as masks or disposable gloves.

The coronavirus has undoubtedly upset the global balance. Lockdowns, forced restrictions in production and transport were a huge challenge for the global economy. However, as the conducted analysis shows, temporary downtimes were quickly averted, and the biggest problem turned out to be not so much the functioning of sea transport but rather rapid increases in sea freight price levels. The confirmation of the high sensitivity of maritime transport allows us to conclude that this is an area that could be more controlled, for example, in terms of statutory price control. The analysis of sea freight price volatility is also an interesting issue worth mathematical analysis and will be an element of further research by the authors.

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