St. Petersburg State University

Graduate School of Management

Master in Corporate Finance Program

Financial reasoning for choosing a supply route under uncertainty: the case of Russian coal exporting company

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Saint Petersburg

2023

ЗАЯВЛЕНИЕ О САМОСТОЯТЕЛЬНОМ ХАРАКТЕРЕ ВЫПОЛНЕНИЯ ВЫПУСКНОЙ КВАЛИФИКАЦИОННОЙ РАБОТЫ

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АННОТАЦИЯ

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Факультет	Высшая школа менеджмента
Специальность	38.04.02 Менеджмент, Корпоративные финансы
Год	2023
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Описание цели, задач и основных результатов	Из-за геополитической ситуации на Россию был наложен ряд санкций в различных отраслях, что кардинально изменило цепочки поставок в стране. В частности, эти изменения коснулись угледобывающей и экспортной отрасли. Чтобы не терять выручку и не сворачивать инвестиционные программы, российские экспортеры угля вынуждены искать новые пути транспортировки угля, кроме Восточного полигона, и эти пути должны быть экономически выгодными. Возможными альтернативами могут быть перевозки по Южному морскому пути (через Суэцкий канал) и по Северному морскому пути. Поэтому возникает вопрос: какие маршруты выбрать для экспорта угля с учетом возможных неопределенностей? Целью исследования данной магистерской диссертации является разработка метода выбора маршрута транспортировки с учетом неопределенностей для российской угледобывающей компании. Для достижения этой цели были поставлены следующие задачи: 1) Анализ теоретических и эмпирических исследований, посвященных выбору

	маршрута доставки и неопределенностям на Северном морском пути. 2) Формулировка методики выбора маршрута перевозки с учетом неопределенностей, а также установление критериев выбора 3) Исследование текущей ситуации экспортеров угля 4) Сбор и обработка данных для оценки затрат и неопределенностей существующих и перспективных маршрутов транспортировки. 5) Расчет стоимости маршрутов с учетом неопределенностей, возникающих на этих маршрутах 6) Предоставление рекомендаций российской компании-экспортеру угля Транспортные расходы на 2023 г. рассчитаны для судов дедвейтом 100 тыс. т на вышеуказанных маршрутах с учетом неопределенности дней доставки по данным, взятым из профессиональных источников: Argus, AXS Dry, Clarkson, отраслевых и корпоративных отчетов, а также статистики из сайт Администрации Северного морского пути. Хотя Северный морской путь считается самым рискованным вариантом среди предложенных маршрутов, с самым высоким стандартным отклонением общих затрат на маршрут, он удовлетворяет обоим критериям модели Марковица для оптимального портфеля. Поэтому в летний сезон рекомендуется весь объем перевозок, которые не могут пройти по маршруту до Ванино, направлять на Северный морской путь.

Ключевые слова	Оценка неопределенности, Северный морской путь, портфель Марковица, реальные опционы, VAR, транспортные расходы

ABSTRACT

Master Student's Name	Ulyana S. Minaeva
Master Thesis Title	Financial Reasoning for Choosing a Transportation Route under Uncertainty: The Case of Russian Coal Exporting Company
Faculty	Graduate School of Management
Major Subject	38.04.02 "Management", Corporate Finance (MCF)
Year	2023
Academic Advisor's Name	Vitaly L. Okulov
Description of the goal, tasks and main results	Due to the geopolitical situation, a number of sanctions were imposed on Russia in various industries, which radically changed the supply chains in the country. Russia had to reorient a significant part of supplies from the European market, mainly to the Eastern one. This situation has greatly increased the load on the railway infrastructure of the Far East Road, which even until 2022 was a bottleneck for cargo importers and exporters. In particular, these changes have affected the coal production and export industry. In order not to lose revenue and curtail investment programs, Russian coal exporters are forced to look for new ways to transport coal, except for the Eastern Road, and these ways should be economically viable. Possible alternatives could be transportation through the Southern Sea Route (through the Suez Canal) and through the Northern Sea Route. Therefore, the question arises: which routes to choose to export coal, taking into account possible uncertainties?

	Thus, the research goal of this paper is to develop the method of choosing a transportation route considering financial reasoning and uncertainties for Russian coal exporting company. In order to reach this objective, the following objectives were achieved: 1) Conduction of the analysis of the theoretical researches and empirical studies devoted to choice of supply route and uncertainties along the Northern Sea Route 2) Formulation of a method concerning the choice of transportation route taking into account the uncertainties as well as establishing the criteria for choice 3) Investigation of the current situation of coal exporters 4) Collection and processing the data to estimate the costs and uncertainties of existing and prospective transportation routes 5) Calculation of the cost of routes, taking into account the uncertainties that arise on these routes 6) Provision of recommendations to a Russian coal exporting company Transportation costs for 2023 were estimated for ships of 100 thousand dwt on the above routes, taking into account the uncertainty of delivery days according to data taken from professional sources: Argus, AXS Dry, Clarkson, industrial and company reports, as well as statistics from website of the Administration of the Northern Sea Route. Although the Northern Sea Route is deemed the riskiest option among the proposed routes, with the

	highest standard deviation for total costs per route, it satisfies both criteria in the Markowitz model for an optimal portfolio. Therefore, during the summer season, it is recommended that the entire volume of traffic which cannot take the route to Vanino should be directed to the Northern Sea Route.
Keywords	Uncertainty estimation, Northern Sea Route, Markowitz portfolio, real options valuation, VAR, transportation costs

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Introduction

Due to the geopolitical situation, a number of sanctions were imposed on Russia in various industries, which radically changed the supply chains in the country. Russia had to reorient a significant part of supplies from the European market, mainly to the Eastern one[1]. This situation has greatly increased the load on the railway infrastructure of the Far East Road, which even until 2022 was a bottleneck for cargo importers and exporters.

In particular, these changes have affected the coal production and export industry. In the first half of 2022, the European communities imposed an embargo on the import of Russian coal: The United States and the EU countries refused it[2], which prompted Russian coal producers to look for new markets, and these markets became the countries of the Asia-Pacific region[3]. However, the key problem for coal exporters has become the delivery of exporting coal[4]: due to the capacity limitations of the railway infrastructure, companies cannot export the entire volume of cargo planned, and companies even have to adjust their production plans in accordance with the railway capacity[5]. This approach to planning production volumes has negative consequences not only for the financial performance of companies, but also for the economy of the producing regions[6].

Also, in addition to the above-described restrictions on the capacity of the railway infrastructure at the Eastern Road, the natural monopoly - Russian Railways - also has a negative impact on the export of coal. Until 2022, the Rules for Non-Discriminatory Access of Carriers to Railway Infrastructure were in force, which are designed to provide all companies with equal access to transportation, and according to these rules, export transportation of coal through the Eastern Road was given priority[7]. However, in 2022, these rules were suspended[8], since it is more profitable for Russian Railways to transport goods with a higher margin than coal has, such as containers and lumber. As a result, the ability to transport coal for export through the Eastern Road has become significantly lower than the volume that was planned to be transported according to the instruction of the President of Russia[9].

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[1] https://delprof.ru/press-center/open-analytics/novaya-logisticheskaya-realnost-kak-izmenilas-zheleznodorozhnaya-logistika/
[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2022.111.01.0070.01.ENG&toc=OJ%3AL%3A2022%3A111%3ATOC
[3] https://www.forbes.ru/biznes/476983-eksport-ugla-v-aziu-posle-embargo-es-ne-vyros-a-upal-cto-budet-dal-se
[4] https://www.kommersant.ru/doc/5681205
[5] https://neftegaz.ru/news/coal/742887-p-zavalnyy-rossiya-mozhet-snizit-dobychu-i-eksport-uglya-v-2022-godu/
[6] https://www.kommersant.ru/doc/5668494
[7] https://seanews.ru/2020/05/28/ru-o-prave-prioritetnogo-dostupa-k-infrastrukture-zh-d-transporta/
[8] https://www.vedomosti.ru/business/articles/2023/02/15/963124-rzhd-prosyat-prodlit
[9] https://neftegaz.ru/news/coal/759985-kuzbass-po-itogam-2022-g-vyvezet-na-rynki-atr-48-5-mln-t-uglya-vmesto-zaplanirovannykh-58-mln-t/

Thus, in order not to lose revenue and curtail investment programs, Russian coal exporters are forced to look for new ways to transport coal, except for the Eastern Road, and these ways should be economically viable. Possible alternatives could be transportation through the Southern Sea Route (through the Suez Canal) and through the Northern Sea Route. Therefore, the question arises: which routes to choose to export coal, taking into account possible uncertainties?

There has long been a heated debate in the business and academic environment about the competitiveness of the Southern Sea Route and the Northern Sea Route, both in comparison with transportation through the Eastern Road, and among themselves.

According to some experts, transportation through the Northern Sea Route can be faster and cheaper than through the Suez Canal, and the Russian government has repeatedly emphasized the importance of developing this direction[10]. At the same time, transportation along the Northern Sea Route comes with a number of risks, and because of these risks, some experts argue that the Northern Sea Route "will never be an alternative route"[11] and the programs for the development of the Northern Sea Route are considered as “nothing more than politics”.

However, there is still no consensus on the expediency of using the Northern Sea Route as an alternative route for the supply of goods, especially for low-margin goods such as coal.

Thus, we see the incredible practical value of an approach that would be developed for choosing the appropriate transportation route in terms of financial measures and taking into account possible uncertainties.

As for the academic relevance of such work, it is explained by the insufficient number of academic articles that would provide a specific tool for choosing a path, not only taking into account the financial justification, but also considering the uncertainties encountered along it. Moreover, there is a shortage of articles that take into account in their calculations of transportation route economic feasibility the uncertainty encountered along the Northern Sea Route. Thus, such work intends to close this research gap.

This paper is aimed to develop a method in the field of supply chain risk management theory. Thus, for researchers as well as for practitioners it should provide the methodological contribution as far as this approach is going to illustrate how a decision-maker can choose the appropriate transportation

[10] https://www.vedomosti.ru/business/articles/2022/08/05/934655-dorozhnuyu-kartu-sevmorputi
[11] https://ria.ru/20180910/1528172961.html

route considering uncertainties in this route as well as the measurement of these uncertainties by real data applicable to Russian coal exporters.

Thus, the research goal of this paper is to develop the method of choosing a transportation route considering financial reasoning and uncertainties for Russian coal exporting company. In order to reach this objective, the following objectives are going to be achieved:

1) To conduct the analysis of the theoretical researches and empirical studies devoted to choice of supply route and uncertainties along the Northern Sea Route
2) To formulate a method concerning the choice of transportation route taking into account the uncertainties as well as establishing the criteria for choice
3) To investigate the current situation of coal exporters
4) To collect and process data to estimate the costs and uncertainties of existing and prospective transportation routes
5) To calculate the cost of routes, taking into account the uncertainties that arise on these routes
6) To provide recommendations to a Russian coal exporting company

The research design is going to be exploratory one because it aims to investigate the potential solution for the problem and it is going to be done as a case study. This master's thesis consists of 4 chapters. The first chapter presents general concepts from the field of decision making under uncertainty and considers models that are used to solve such problems. Chapter 2 provides an overview of the coal mining industry and Russian coal export issues. Also, in the second chapter, the uncertainties and studies that were made as part of the study of the Northern Sea Route are considered. Chapter 3 describes the research methodology: it presents the proposed models, as well as data sources, descriptive statistics of the source data, describes the approach to forecasting these data, and the results of forecasting. Chapter 4 highlights the results of calculations for the models described in Chapter 3, describes the practical and theoretical value of this study, and outlines the limitations of the study and directions for future research.

Chapter 1. Literature Review

Decision making under uncertainty in supply chain management

Supply chains have always been vulnerable to anticipated and unforeseen events that threaten their profitability and business continuity. Therefore, scientists and practitioners have shown a growing interest in identifying the root causes of these disorders and exploring strategies to mitigate the associated risks. This interest has grown over the past two decades, driven by three main factors. First, lean management and just-in-time methods used in manufacturing and logistics have led to efficiencies, but have also exposed supply chains to unpredictable events by allowing area for error and minimal adjustment (Snyder et al. 2016). Second, increasing globalization and limited vertical integration of companies have increased the complexity of supply chains and made them more vulnerable to risk factors (Behzadi et al. 2018). Finally, there have been many incidents and situations ranging from natural disasters (Chopra and Sodhi 2014).

Risks and uncertainties in supply chains

Uncertainty is a common factor in every business process and decision. Any incorrect assessments or misjudgments can result in unexpected outcomes, which may have significant consequences if not detected in a timely manner.

Uncertainty is the fundamental feature of the system, indicating the lack of full knowledge of its conditions and evolution. The term risk has many definitions, with Knight (1921) linking it to quantifiable uncertainty.

Despite the growing importance of the topic, only a limited number of authors have explicitly defined supply chain risk. These definitions are based on the assumption that supply chain risk is an event-driven concept, which aligns with the traditional understanding of risk as being related to the probability of disruptive events occurring. In the context of supply chain risk management, events are characterized by their likelihood and the consequences they have on the supply chain. The cause of the risk is not relevant in this classification, as it can originate from within a single firm, its supply chain, or the supply chain's environment. Some authors focus on the impact of an event on a single firm, while others examine the performance of the entire supply chain, which can be affected by cascading effects that propagate throughout the network[12]. Several authors have proposed definitions of supply chain risk, including March and Shapira (1987), who define it as the variation in the distribution of possible outcomes, their likelihood, and their subjective values. Zsidisin (2003)

[12] S. M. Wagner and C. Bode. An empirical examination of supply chain performance along several dimensions of risk. Journal of Business Logistics, 29:307–325, 2008.

proposes a definition that relates the occurrence of an incident to the affected companies' inability to cope with the consequences. Juttner, Peck, and Christopher (2003) define supply chain risk as the possibility and effect of a mismatch between supply and demand. However, most conceptual research focuses on categorizing triggering events, which are often synonymous with supply chain risk and serve as a starting point for risk identification.

It is crucial to continuously monitor and manage uncertainties. As the number of uncertainties continues to rise, the significance of risk considerations has also increased. Consequently, the importance of managing supply chain risks has become more critical.

Supply chain risk management

Although there is no universally accepted definition of SCRM, there is generally more consensus than disagreement between the terms. In contrast to risk, SCRM is generally defined as a set of actions leading to a specific outcome, emphasizing coordination and collaboration between supply chain partners as a necessary prerequisite. These actions are generally grouped under the term "management" or specified individually, including risk identification, assessment, mitigation and monitoring. The intended outcome of SCRM can include addressing negative impacts or strengthening positive aspects of the supply chain, e.g. reducing vulnerabilities and the probability of risk (Juttner, 2005; Martin and Peck, 2004) or ensuring profitability and continuity (Tang, 2006; Manuj and Mentzer, 2008).

To encompass all these elements, this master thesis proposes a comprehensive definition of SCRM as joint and synchronized initiative among all stakeholders operating within a supply chain, aimed at recognizing, evaluating, minimizing, and supervising potential risks in order to improve the strength and durability of the supply chain while also upholding profitability and business continuity.

Detecting and managing risks is essential to prevent disruptions from occurring. Although managing force majeure disruptions can be challenging, companies can use risk assessment strategies such as identifying risk indicators, the principles of Total Quality Management (TQM), and sharing information among supply chain partners to estimate and prepare for such events. It is crucial for companies to have contingency plans in place in the event of any disruptive occurrence. Organizations should conduct regular audits to monitor the performance of their supply chains. Adopting these principles helped Toyota minimize disruptions due to product recalls. This has been well-documented in research by Dyer and Nobeoka (2000).

Types of supply chains risks

There have been various classifications introduced in recent literature pertaining to supply chain risks. Authors such as Chopra and Sodhi (2004), Tang and Musa (2011), Ho et al. (2015), and Quang and Hara (2017) have proposed distinct categories of potential supply chain risks. For instance, Chopra and Sodhi (2004) identified nine risk categories, including Disruptions, Delays, Systems, Forecast, Intellectual property, Procurement, Receivables, Inventory, and Capacity. In contrast, Quang and Hara (2017) classified seven groups of risks as External, Time, Information, Financial, Supply, Operational, and Demand risks. The identified risks encompass a wide range of factors, such as natural disasters, terrorism, war, inflexibility of supply source, inaccuracies in forecasting, economic downturns, fire accidents, communication breakdowns, inflation, supplier issues, accidents, and demand variability, amongst others.

In Klibi's (2010) study it was found that uncertainties and risks in the supply chain can be divided into three types: random uncertainty, hazard uncertainty, and deep uncertainty, each of which tackles risks related to demand fluctuation, high-impact unusual events, and severe disruption respectively. These types of risks can be further categorized into four areas, namely demand, supply, process, and structure areas. According to Tang (2006), supply chain risks can be categorized into two types: operational risks and disruption risks. Operational risks arise from inherent uncertainties such as unpredictable customer demand, supply, and costs. Disruption risks, on the other hand, result from major disruptions caused by natural or man-made disasters. Rao and Goldsby (2009) have identified a typology of risk sources, including environmental, industrial, organizational, problem-specific, and decision-maker related factors. Literature on supply chain risk management (SCRM) has been collected and classified by Tang (2006), Kouvelis et al. (2006). While many qualitative analyses and quantitative models of SCRM exist, most quantitative models focus on managing operational risks, while disruption risks are often overlooked (Tang, 2006). Although demand fluctuations are frequently discussed in the literature, few papers address how to deal with catastrophic events. Woodruff and Voß (2006) have made an initial attempt to apply PH to a supply chain production planning problem with significant disruptions.

In stochastic supply chain environments, postponement strategies offer more flexibility and options for decision-making to mitigate risks. By incorporating longer shipping times to establish additional time buffers, postponement can effectively manage supply chain disruptions, as identified by Fan et al. (2014). However, the optimal expected annual supply chain costs can only be determined through enumeration, which is limited to small-scale problems with a limited number of scenarios.

Additionally, the correlation between optimal transportation modes and the likelihood of catastrophic scenarios has not been investigated yet.

Measurement of risks in supply chains

Global supply chains are becoming more complex and uncertain, which poses a challenge for supply chain risk management (SCRM). Despite this, quantifying and modeling SC risks remains a difficult task, as highlighted by Heckmann et al. (2015) and Ho et al. (2015). To address this issue, this research aims to provide decision support to SC executives by quantifying disruption risks and modeling SCs in stochastic environments.

The importance of considering environmental factors and sustainability in SCRM is emphasized by Heckmann et al. (2015) and Fahimnia et al. (2015). In particular, sustainability risk is identified as an emerging area in SCRM by Fahimnia et al. (2015). As a result, ocean carriers have increasingly turned to slow steaming as a more eco-friendly and cost-effective transportation mode, as noted by Meyer et al. (2012). However, some shippers are hesitant to adopt this practice due to the longer transportation time and associated increase in pipeline inventory, as discussed by Maloni et al. (2013).

Real options approach in supply chains

A real option is a manager's ability to use the flexibility built into an investment project (Bukhvalov, 2004). Using real options, managers get the opportunity to actively manage the risks that the company is facing. The starting point for the study of real options is considered to be 1977, in which the work of S. Myers “Finance Theory and Financial Strategy” was published (Myers, 1977). In it, the term "real options" was first used in the context of strategic corporate planning.

Since then, research in this area has advanced significantly, the concept has been expanded to cover various types of decision making under conditions of uncertain future, and the method of real options has gained popularity for evaluating investments, projects and companies.

The concept of a real option may reflect:

1) a phenomenon used by managers in everyday practice (often unconsciously);
2) tools for the development and adoption of strategic decisions;
3) a method that allows you to adjust (refine) the net present value of the project in order to obtain a more adequate assessment of real assets and manage them.

The evaluation of investment projects by the method based on real options is based on the assumption that any investment opportunity can be considered as a financial option, that is, the company has the right (but not the obligation) to perform any action with the asset over time: create, buy, sell and etc. The general definition of real options is given in the article (Bukhvalov, 2004) as "the ability to make flexible decisions under conditions of uncertainty".

Today, the real option is used as a standard instrument for cushioning financial risks in companies. Integrating real and financial options should greatly improve supply chain efficiencies, especially in a global manufacturing environment. This should not only apply to strategic/tactical decisions such as supplier selection, change of supplier, but also to operational decisions such as speculative stocks, billing currency, etc. This offers the opportunity to integrate different processes in the supply chain.

Scholars identified the following six generic types of real options (Cohen and Huchzermeir, 1999):

- Wait/postpone
- Expand
- Exit
- Switch
- Improve

In Article “Real options in Operations Research” (Trigeorgis and Tsekrekos, 2018) authors considered several fields of operations research that is connected to supply chain management in broad meaning. First field is about production and manufacturing and the second one is supply chain and logistics itself.

In the presence of stochastic output demand or input price uncertainty, flexible production systems that allow production schedules and allocation of resources to be adaptive to new information and to unexpected changes in key underlying variables have been used to enhance the robustness and efficiency of operations. Option-based methods proved well-suited for modeling and highlighting such flexible production systems. In a global economic environment, the decision whether to partially or completely outsource manufacturing operations (and for how long) also proved a valuable option to decision-makers.

The flexibility inherent in production scheduling, manufacturing operations management (e.g. in-house or outsourced), supply contracts or corporate resource allocation in the face of demand, price or yield uncertainty has been a common focus of RO methods in OR (Li & Kouvelis, 1999, and Kamrad & Ernst, 2001).

As globalization has reshaped the operations management of both manufacturing and service organizations, outsourcing and ownership alternatives, production planning and resource allocation strategies acquired increased importance in OR.

On optimal production and resource allocation, Van Mieghem (2007) presents a single-period theoretical framework of a risk averse decision-maker with general utility preferences and a set of resources with uncertain end-of-period value, who can allocate resources in either a dedicated, serial or parallel network configuration. Building on portfolio theory, the author shows how the degree of risk aversion and the chosen network configuration drive the allocation of resources so as to mitigate risk through operational hedging and reducing profit variability. He concludes that risk aversion causes over-adjustments in resource positions.

Ball, Deshmukh, and Kapadia (2015) propose a framework to endogenize the interaction of heterogeneous agents who coordinate in a distributed production system. In their model, tasks of varying utility upon completion arrive randomly to a task agent who decides which one to allocate/send to a resource agent, based on her preferences. The authors formulate the problem as a real option game, showing that the production system converges to an equilibrium state that improves the performance for both agents.

On inventory policy, Berling and Rosling (2005) consider typical fixed replenishment quantity (R,Q) policies in a real options framework. Assuming the Consumption CAPM holds (Breeden, 1979), the authors suggest simple adjustments to R and Q to account for the systematic risk component of stochastic demand and stochastic purchase price (both following a Geometrical Brownian Motion). They conclude it is the systematic risk of the purchase price (not demand) that has a significant effect on optimal policy. In later work, Berling (2008) examines the same problem, assuming deterministic demand and that the log of purchase price follows a (stationary) Ornstein-Uhlenbeck process, a more appealing assumption for price evolution.

Secomandi (2010) examines optimal inventory-trading policy for a risk-neutral merchant that stores energy and natural resources such as natural gas in a warehouse with space and injection/withdrawal capacity limits. He shows that if the resource spot price evolves according to an exogenous Markov process, the optimal inventory-trading policy involves two (price and stage-dependent) stock targets that partition the available inventory/price space at each stage into three regions: one where it is optimal to buy and inject, one where it is optimal to do nothing, and one where it is optimal to withdraw and sell the resource to the market.

Bilateral options that suppliers and manufacturers grant each other as part of the agreed terms of a supply chain configuration have been thoroughly examined using RO methods in several operations research studies. Moreover, the option to change suppliers or the extent to which firms in a supply chain collaborate or compete for better agreement terms has been fruitfully modeled as an 'option game'.

The configuration of supply chains and the optimal contracting arrangements among various supply chain parties have been an important focus of ongoing research efforts that employ RO modeling and bargaining/game-theoretic tools

Real Options provide an intuitive way of incorporating flexibility in the management of supply chain operations (Wallace & Choi, 2011). Kamrad and Siddique (2004) and Burnetas and Ritchken (2005) provide important early contributions that evaluate the flexibility inherent in supply chain contracts using real options. Kamrad and Siddique (2004) analyze "supply contracts in a setting characterized by exchange rate uncertainty, supplier-switching options, order-quantity flexibility, profit sharing, and supplier reaction options". A producer facing capacitated production and inventory ability requires a production input (component or raw material) that can be supplied by M different suppliers. The producer can adjust the production rate over time and (as suppliers might be abroad) the order quantities from each supplier in the face of fluctuating exchange rates so as to meet product demand. Suppliers require a supplier-specific penalty if producer order-level changes exceed a certain level. The authors express the optimal policies for the producer– supplier contracts as the solution of a system of $M + 1$ Bellman equations using no-arbitrage arguments. Their approach endogenizes profit-sharing, which is allowed to be time variant and intuitively highlights that suppliers essentially hold compound "reaction" options to address the order-quantity risk generated by the producer's flexibility to switch among suppliers.

In an empirical paper, Osadchiy, Gaur, and Seshadri (2015) show that the structure of supply chain networks affects the systematic risk of chain members, mediating the effect of economy-wide shocks on industry or firm sales.

Burnetas and Ritchken (2005) consider a setting with one manufacturer whose only access to the product market is via a single retailer. In industries characterized by long lead times, high demand uncertainty and short selling seasons (such as apparel, toys, etc.), it is common for manufacturers to provide retailers reordering (call) options that allow purchasing additional goods at a fixed price for a set time; they also provide retailers return (put) options that give the right to return unsold goods at a set salvage price. The manufacturer's problem is to design the terms of the reordering and return options and establish their prices, along with the wholesale price. The authors highlight that valuation of these options is different from the usual Black–Scholes–Merton setting (where exercise of new options does not affect the underlying asset price). As the underlying asset in this setting is the good supplied by a monopolist, its wholesale price is affected by whether or not options are offered to the retailer, whose optimal exercise actions have a "feedback effect" on the profit of the monopolist.

Assuming a one-period world with a linear inverse demand function and a Bernoulli process for the uncertain end-period demand realization, Burnetas and Ritchken (2005) show that the granting of options by the manufacturer achieves better supply-chain coordination and diminishes retail price volatility, but it could also harm the retailer's profitability in case of high demand uncertainty.

In Zhao, Yang, Cheng, Ma, and Shao (2013), one or more retailers complement their order call options with immediate purchases from a spot market (such as a business-to-business, B2B, e-marketplace). Assuming manufacturers and retailers are pricetakers in the spot market (no "feedback effect") and abstracting from their risk-preferences, the authors provide a value-based pricing scheme for order options in the supply chain.

Inderfurth and Kelle (2011) also consider the optimal mix of long-term procurement contracts and spot market orders, while in Wu and Kleindorf (2005) one buyer and multiple sellers may either contract for delivery in advance or they may buy and sell some or all of their input or output in the spot market. Assuming risk-neutrality and heterogeneous sellers with perfect knowledge of the buyers demand function, the authors characterize the price of capacity options, the value of managerial flexibility and the efficiency and sustainability of B2B exchanges.

The question of optimally integrating contractual and spot market procurement sources was solved in (Mahapatra, Bisi et al., 2016). Authors developed models to determine the optimal procurement policy in continuous time across two sources for specified price and risk aversion parameters. They showed that the optimal strategy prescribes simultaneous procurement from both contract and spot market sources. Their research question is the following: what should be the modelling framework, underlying parameters and contractual settings that will facilitate dual procurement strategy which is used to manage the risks of procurement expenses.

Models are developed to determine the optimal procurement policy in continuous time across the two sources for specified price and risk aversion parameters. Authors examined cases when the contract price parameter is exogenously specified and when it is endogenously adjusted according to the procurement policy. They showed that the optimal strategy prescribes simultaneous procurement from both contract and spot market sources. Then they provided the applications of the model on illustrative datasets, which showed insights into the relative advantages of integrating the two sources of procurement over a “pure contract” or a “pure market” procurement source.

The Supply Chain Finance challenge of Commodity Price Volatility (CPV) has been addressed in a recent study (Pellegrino, Costantino, Tauro, 2018) from a supply chain-oriented perspective. The study investigates the effectiveness of two Supply Chain Risk Management (SCRM) strategies, namely, Switching suppliers and Substituting Commodities, in mitigating CPV and the factors that may affect their value through a simulation analysis. The study also developed and tested a Real Option Valuation (ROV) model on real cases of CPV mitigation experienced by a large multinational company in the Fast Moving Consumer Goods (FMCG) industry. The results indicate that Switching suppliers and Substituting Commodities are effective in mitigating CPV, but their convenience is influenced by specific conditions such as the relative values of long-term commodity prices, purchasing volume, and sunk cost required to build flexibility. However, the study highlights a research gap in assessing how supply managers can combine these strategies into a portfolio of risk mitigation strategies and investigate their combined value.

Approaches to find the route

The construction of routes of vehicles that provide, with the least expenditure of time and means, the delivery of goods in the established volumes and within certain constraints, is one of the most important tasks of the transport logistics[13] [14].

The optimal route is considered to be the route by which it is possible to deliver passengers or cargo in the shortest possible time and the terms provided for by the delivery schedules with the minimum expenditure of time and cost.

Deterministic models

The choice of a transport route is a particular classical problem of the general group of mathematical programming problems. This type of problem is called "transport problem", the essence of which is

[13] Benson D., Whitehead J. Transport and delivery of goods. - Transport, 1990. - 279 p.

[14] Belenky A.S., Levner E.V. Application of models and methods of scheduling theory in problems of optimal planning in freight transport: A review // Automation and Telemechanics. - 1989. - No. 1. - P. 3-77

to find an economical plan for transporting a homogeneous product from production points to consumption points.

Types of transport tasks:

1. Transport problem according to the criterion of transportation cost.
2. Transport task according to the criterion of time.
3. The transport problem for determining the shortest distance along a given road network and the problem for introducing the maximum flow in the circuit.

The majority of literature on supply chain management decisions relies on deterministic models that only consider a single hazard scenario, such as a worst-case or most probable scenario. Several authors, including Cova and Johnson, Kim and Shekhar, Kalafatas and Peeta, Xie et al., Karoonsoontawong and Lin, Bretschneider and Kimms, Wang et al., and Zhao et al., propose using lane-based routing and/or crossing-elimination decisions as supply management strategies to reduce delays at intersections by temporarily transforming them into uninterrupted traffic flow facilities. While some authors present models based on network flows, others use a CTM-based DTA model. Wang et al. present a multiple objective optimization model that considers supply priorities and the setup time for the contraflow operation. Zhao et al. propose an integrated CTM-based optimization model that reconfigures one-way traffic networks and implements lane-based non-diversion routing with crossing-elimination at intersections to minimize the network clearance time.

The trend in supply chain management optimization techniques is evolving (Zheng et.al., 2015). The initial phase was dominated by deterministic methods, with mixed integer programming being the preferred modeling approach over dynamic programming, priority list, Lagrangian Relaxation, and others. However, deterministic models, which assume perfect information, generated unrealistic outcomes. Due to the volatility of parameters, fluctuating demands, and intermittent economic factors, deterministic methods alone were insufficient to capture the entire supply chain's dynamics (Altintas et.al., 2018).

Stochastic models

Stochastic optimization (Birge and Louveaux, 2011), also referred to as stochastic programming a mathematical framework that enables modeling of decision-making in situations of uncertainty, is. Its origins can be traced back to the 1950s when George B. Dantzig, the pioneer of the simplex algorithm for linear programming, published a paper on "Linear Programming under Uncertainty." In this paper, Dantzig highlighted the need for a modeling framework that could handle uncertain demands in the allocation of carrier fleets to airline routes. Since then, stochastic programming has become a significant area of research for the operations research and mathematical programming community, with numerous theoretical and algorithmic advancements summarized in classical textbooks (Birge and Louveaux, 2011; Shapiro et al., 2014). With the development of computational methods, stochastic programming has found applications in diverse fields such as financial planning, electricity generation, supply chain management, climate change mitigation, and pollution control (Wallace and Ziemba, 2005).

A stochastic optimization problem is an optimization problem in which the objective function or constraints depend on random parameters. Traditionally, the solution of an optimization problem is understood as a deterministic solution that satisfies certain probabilistic criteria.

There are two main types of stochastic optimization problems (Timofeeva, 2020): with an objective function depending on a random parameter and with restrictions depending on a random parameter.

Some authors also study problems containing random parameters both in the objective function and in the constraints, but in most works, many applied problems are related to stochastic optimization problems of the first or second type.

Numerous studies have been conducted to improve the resilience of supply chains through various design and operational strategies, as well as stochastic-based solution methodologies. For instance, Namdar et al. (2018) developed a stochastic mathematical programming model that utilized four strategies to achieve SC resilience, while Torabi, Baghersad, and Mansouri (2015) employed proactive resilience strategies in their bi-objective two-stage stochastic programming model. Jabbarzadeh, Fahimnia, and Sabouhi (2018) adopted three common strategies for SC resilience in their bi-objective stochastic optimization model, and Baghalian, Rezapour, and Farahani (2013) formulated a stochastic mathematical model for designing a robust SC against various disruptions. Fattahi, Govindan, and Maihami (2020) presented a new metric for quantifying SC resilience using a two-stage stochastic programming model, and Namdar et al. (2020) developed a three-step framework to enhance SC resilience. Sabouhi et al. (2021) also formulated a stochastic programming model that incorporated different resilience strategies. Additionally, Dixit, Verma, and Tiwari (2020) used a CVaR measure within a simulation-based approach to assess SC resilience before and after disruption events. The use of CVaR in achieving SC resilience aims to address the worst possible disruption events. Verderame and Floudas addressed demand uncertainty in a single production facility using the robust optimization framework and conditional value-at-risk (CVAR) theory, which was also utilized by Carneiro et al. for risk management in an oil supply chain. Verderame and Floudas extended their work to integrate operational planning and medium-term scheduling under demand and processing time uncertainty. Overall, explicitly considering parameter uncertainty greatly enhances the reliability of planning decisions.

It is worth noting that stochastic optimization problems are notoriously difficult to solve, except for small instances. Scenario analysis is a common approach to dealing with stochastic problems, which breaks them down into solvable sub-problems. Progressive hedging (PH) has been successfully applied to solve various stochastic programming problems, including network, fishery, power system optimization, resource allocation, and lot-sizing problems. PH is a solution technique that finds a solution that performs well for all scenarios of the multi-scenario problem. It utilizes the variable split form of the multi-scenario program and integrates the nonanticipativity constraints of a stochastic model into the objective function as penalty and multiplier terms. However, exact solutions of the scenario problems are rarely used because increasing the penalty slows down the algorithm. Helgason and Wallace (1991) propose a scenario aggregation procedure that solves the individual scenario problems only approximately, using an integrated application of a Lagrangian approach. Lokketangen and Woodruff (2001) provide a first implementation of general-purpose methods for finding good solutions to multistage, stochastic mixed-integer programming problems using PH and tabu search. They note that without a good, integer-feasible solution during the initial iteration of PH, the solution will hardly be integer feasible.

Li, Ierapetritou, and Verderame, among others, emphasized the significance of explicitly considering various forms of parameter uncertainty in supply chain management problems. Two-stage stochastic programming, which involves an outer deterministic model and an inner recourse model dealing with uncertain parameter realization, is one approach to modeling parameter uncertainty. Gupta and Maranas, Levis and Papageorgiou, Wu and Ierapetritou, Colvin and Maravelias, and Al-Qahtani and Elkamel have all utilized two-stage stochastic programming to address parameter uncertainty in planning problems. However, Clay and Grossmann argued that decoupling the problem in this manner is often suboptimal and computationally inefficient. Instead, they proposed parametric programming, which is based on sensitivity analysis and aims to define a function that maps uncertain parameter values to an optimal solution for the entire uncertain parameter space. Pistikopoulos, Dua, and Ryu et al. demonstrated that parametric programming can effectively address certain variants of the planning under uncertainty problem.

Parametric programming can be challenging for large-scale industrial problems due to the iterative approach and computational time required. Chance constraint programming, on the other hand, has been utilized by researchers such as Petkov and Maranas, Li et al., and Mitra et al. to solve specific aspects of supply chain management under uncertainty without the same potential computational burdens. However, chance constraint programming does not guarantee the feasibility of obtained solutions with uncertain parameters.

It should be noted that one of the classical problems of stochastic optimization is the optimal Markowitz portfolio (Trofimova, 2020). However, in the literature on supply chain management, there is very little research that has applied this approach, despite its ease of application and advantages of application. Portfolio theory offers the advantage of exploring optimal combinations of portfolio costs and risks, resulting in an efficient frontier curve that comprises the best combinations. Any portfolio on this curve has the best performance, and there is no other portfolio with the same cost and lower risk or the same risk and lower cost. If a reference portfolio is located to the right of the efficient frontier, it will have an inefficient cost-risk combination. The closer the reference portfolio is to the efficient frontier, the better the power generation mix. The risk minimization portfolio and the cost minimization portfolio are situated at the ends of the efficient frontier, representing the best options for two different objectives. Therefore, the decision maker has a set of portfolios on the efficient Markowitz frontier, and he chooses the appropriate portfolio for him depending on his appetite for risk and the desire to reduce costs in the logistics route

Thus, in (Levinson, 2013), the study presents a model of individual route selection, in which choosing a set of routes instead of a single route is the best strategy for a rational traveler who cares about both travel time and delays when faced with stochastic network conditions. In a recent work (Kellner, 2019), an optimal supplier selection model was built using the Markowitz portfolio method. In Sadjadi's (2007) paper, a practical and efficient algorithm is proposed for optimal transportation planning of hazardous materials. The optimal solution typically involves minimizing the expected cost of various alternatives. However, there may be a desire to simultaneously minimize the risk associated with the decision. To address this, the paper applies the efficient frontier approach to transportation of hazardous materials. The author demonstrates that this method is capable of minimizing both the expected cost and risk, providing a range of optimal solutions for decision-makers to consider.

Chapter Conclusion

In this chapter, the main concepts in the field of decision-making under uncertainty in the framework of supply chain management were considered, the concepts of "uncertainty" and "risk" were defined, and the main risks in supply chain management were described.

Despite the abundance of uncertainties in this area, most of the choice of path is made using a deterministic approach. However, stochastic models (taking into account uncertainty) are gaining more and more popularity among researchers.

At the same time, in the modern scientific environment in the field of supply chain management, the Markowitz efficient frontier model is rarely used as a stochastic model, despite its important advantage in that it allows the decision maker to make a choice regarding the portfolio of routes. Thus, my research aims to close this research gap by applying the Markowitz efficient frontier method to the route selection problem.

Moreover, a literature review was conducted on the application of the real options approach. Many studies show that real option measures the flexibility in the supply chain, however, at present, there are still few studies conducted on the evaluation of flexibility in the choice of transportation route. Therefore, this master's thesis aims to close this research gap as well.

Chapter 2. Coal Exporting Industry Overview

Coal is an extremely important energy asset. Coal still occupies a leading position in energy generation: oil is in first place with 31%, followed by coal with 26% and natural gas closes the top three with 23%[15].

General concepts of coal production industry

According to the ASTM (American Society for Testing and Materials) classification[16], four main types of coal are distinguished depending on the stage of transformation: lignite (brown coal), sub-bituminous coal, bituminous coal (bituminous coal) and anthracite. From an economic point of view, it is more useful to consider the types of this fossil in two categories: thermal coal and coking coal. The fundamental difference between them lies in the application they have found in production.

Depending on the type, coal is used in power generation, metallurgy, chemical, construction and gas industries[17]. The following three industries represent the greatest demand for the products of coal mining companies.

1. Power generation. Generating stations use thermal coal (Steam Coal) represented mainly by bituminous coal due to the combination of the optimal balance of heat transfer and cost, which led to its most widespread use. Lignite is used less as its heat generation capacity is rather low and emissions from combustion side effects are quite high. Nevertheless, in some developed countries, the use of brown and sub-bituminous coal is becoming more widespread, since the content of sulfur, which causes significant environmental damage, is less in them than in hard coal. Anthracite is an excellent fuel: it emits very few combustion by-products, produces virtually no smoke and generates a significant amount of heat. However, its widespread use is hampered by the rather high cost of extraction and low prevalence in nature.
2. Metallurgy. About 75% of all steel produced in the world is smelted using metallurgical coke, which is formed during the processing of coal at high temperature without access to oxygen (coking process). For the manufacture of coke, special coking coal is used, which is quite rare - only about 20% of hard coal is subject to coking. It is this type of coal that is extremely important in the metallurgical industry.

[15] Petrenko I.E. Russia’s coal industry performance for January – December, 2022. Ugol’, 2023, (3), pp. 21-33. DOI: 10.18796/0041-5790-2023-3-21-33.
[16] https://archive.org/details/gov.law.astm.d388.1998
[17] https://www.suek.ru/our-business/coal

3. Recently, the use of coal in the chemical industry has become more widespread. In particular, in the process of coking, coke gas is obtained as a by-product, which is later used as an alternative to natural gas, coal tar and benzene. Brown coal and anthracites are also actively used for the production of aromatic hydrocarbons, synthetic substitutes for natural gas and gasoline.

Worldwide production coal industry

Leadership in the sector depends on reserves, production and production volumes, exports and imports. Today, about 75% of all world reserves are concentrated in 5 countries: the USA (249 billion tons), Russia (162 billion tons), Australia (150 billion tons), China (144 billion tons) and India (111 billion tons).

In total, the world produces about 8.3 billion tons of coal per year. More than 40% of all coal (3.5 billion tons per year) is produced by China. In second place is India with 748 million tons annually, followed by the United States - 642 million tons, Australia - 502 million tons, Indonesia - 488 million tons and Russia - 437 million tons.

However, only 20% of the total production is sold on the world market. Many countries are focused on meeting their own needs rather than exporting.

At the moment, there are three leading exporters of coal products: Australia, Indonesia and Russia - they account for 28.8%, 25.6% and 17.9% of exports, respectively.

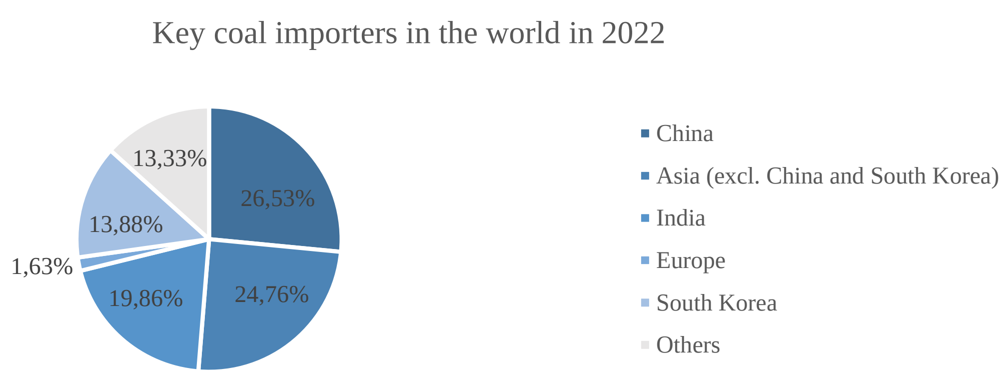

Figure 1. Key coal imoirters in the World. Source: IHS

At the same time, about 70% of coal traded on the world market is shipped to Asia. China, Japan and India account for the largest shares of all imports - 19.5%, 14.6% and 14.5% respectively.

Russian coal production industry

Russia is one of the world leaders in the production and export of coal, it ranks sixth in the world in terms of coal production after China, the USA, India, Australia and Indonesia (Russia accounts for about 5% of world coal production) and third in coal export after Indonesia and Australia (on the international market, Russia accounts for about 15%).

According to the Russian Ministry of Natural Resources, coal reserves in the Russian Federation are located within 22 coal basins and 146 individual deposits. Hard coal reserves are estimated at 120.4 billion tons (of which 50.1 billion tons are suitable for coking, brown coal reserves are 146 billion tons. Anthracite reserves are taken into account in the amount of 9 billion tons. About 174.6 billion tons (63%) coal reserves are suitable for open pit mining conditions

According to the "TEK", as of 01/01/2022, coal mining in the Russian Federation was carried out by 176 coal enterprises, including 50 mines and 126 open-pit mines. The production capacity for coal mining at the beginning of 2022 is 523 million tons.[18]

In Russia, coal is consumed in almost all subjects of the Russian Federation. The main consumers of coal in the domestic market are power plants and coking plants. Of the coal-producing regions, the largest producer and supplier of coal is the Kemerovo region - Kuzbass, in 2022, about half (50.8%) of all coal mined in the country, as well as 57.1% of coking coal grades, were produced here. Kuzbass is also the largest exporter of Russian coal (57.1%), including for coking.

According to Rosstat, coal production in Russia in 2022 amounted to 437 million tons. It increased by 5 million tons, or 1.2%, compared to 2021.

[18] https://minenergo.gov.ru/node/433

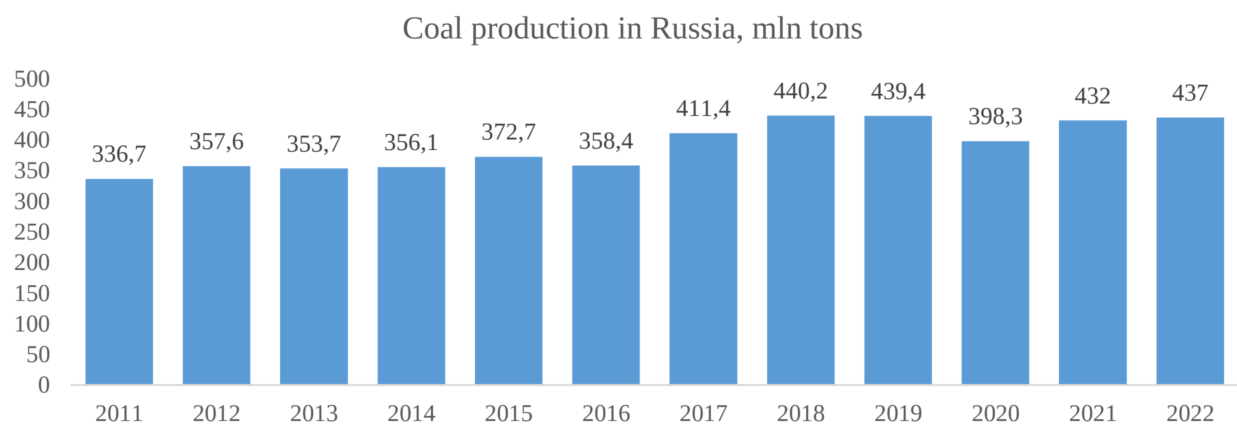

Figure 2. Coal production volume in mln tons, 2011-2022. Source: Rosstat

The largest coal mining companies in Russia with the volume of production for 2022 are presented in the chart

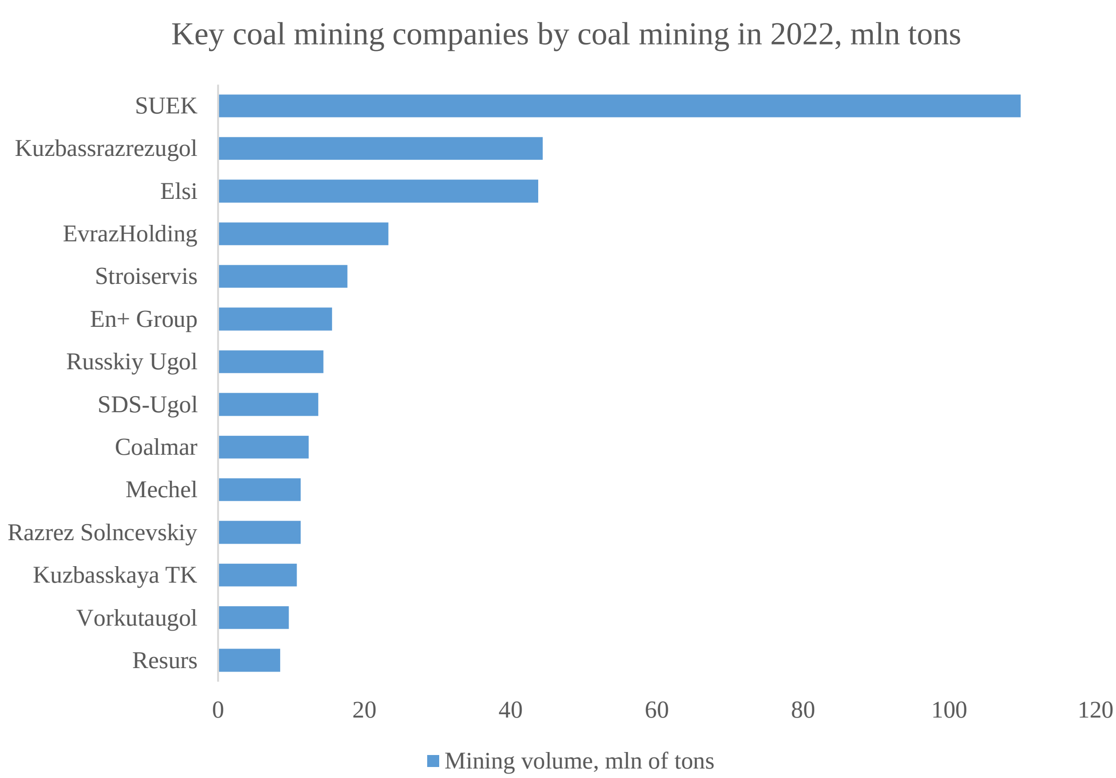

Figure 3. Key coal mining companies in Russia in 2022. Source: Central Dispatching Office of the Fuel and Energy Complex

The companies listed in the Figure produced a total of 403 million tons of coal in 2022, which is 90.9% of the total coal production in Russia.

The total volume of Russian coal exported in 2022, according to Russian Railways[19], amounted to 197.4 million tons. This is 15.2 million tons, or 7.2% less than a year earlier

Exports account for 52.6% of the shipments of Russian coal. The main share of exports falls on thermal coals - 169 million tons (83.8% of total coal exports), the share of coking coals (32.7 million tons) in total exports amounted to 16.2%.

In Russia, the largest coal exporting companies are: SUEK, ELSI, Kuzbassrazrezugol, Solntsevsky mine, SDS-Ugol, Stroyservis, Mechel, Resource, Raspadskaya coal company, Kuzbasskaya TK:

- The strategy of SUEK JSC involves the development of exports primarily in the direction of the Asia-Pacific countries. At the same time, SUEK strives to maintain its position in the Atlantic region. Deliveries to the Asia and Oceania market are expected to increase steadily due to low growth in coal consumption in Europe[20]. The company has captive coal transshipment facilities in the port of Vanino, Vostochny and Murmansk, and also has its own fleet of gondola cars. According to the structure of coal exports, the company sends most of it to China and Southeast Asia.
- Kuzbassrazrezugol conducts coal mining mainly in the open pit in the Kemerovo region. In 2022, more than 71.3% of the company's total shipments were exported. The company has captive facilities in the port of Vostochny and Ust-Luga. The company sends most of the volumes to Western destinations, Asian destinations account for up to 25% of export volumes
- SDS-Ugol is engaged in the extraction of thermal and coking coal both by open and underground methods. The company owns open-pit mines, two mines and four processing plants in the Kemerovo region. According to 2022 data, about 95% of products companies are exported. The key sales markets are European countries. In 2018 SDS-Ugol Holding Company and Russian Railways signed an investment agreement on the construction of the Sukhodol coal port in the Far East, which is scheduled to open in September 2023[21].
- EVRAZ is one of the largest producers of coking coal in Russia. Extraction, enrichment, production of concentrates is carried out at the mines and enterprises of the Raspadskaya Coal Company in Novokuznetsk and Mezhdurechensk, as well as at the Mezhegeyugol enterprise located in the central part of the Tyva Republic in Eastern Siberia. The company plans to

[19] Source: Railway statistics
[20] https://expert.ru/expert/2022/50/ekologiya-sotsprogrammy-i-upravleniye-strategiya-ustoychivogo-razvitiya-suek-v-2022-godu/
[21] https://www.korabel.ru/news/comments/otkrytie_novogo_porta_suhodol_v_primore_planiruetsya_v_sentyabre.html

increase shipments through ports in Asia, as China and India have the most room for growth. In 2020, GMMC Evraz and OTEKO Group of Companies signed an agreement for the transshipment of coal through the Taman Bulk Cargo Terminal. It is expected that the coal exported through this terminal will be sold in the Asian market[22].

Coal exports transportation problem statement

Of the total exported volume of coal, 181.7 million tons (92.0% of the total exported volume) were shipped through seaports and 15.7 million tons (8.0%) through border crossings[23].

The main coal transshipment ports are ports in the East direction, ports in the West direction (Arctic and Baltic basins) and ports in the South direction.

Far East Route

The eastern road of Russian Railways is the main logistics corridor for shipping coal mined in Kuzbass for export. It includes the Baikal-Amur and Trans-Siberian Railways (BAM and Trans-Siberian). Currently, the modernization of the Eastern test site is being carried out, which is one of the largest infrastructure projects in Russia. It involves the construction of additional generation and power grids.

The carrying capacity of the Eastern road in 2022 amounted to 158 million tons. In 2023, it should increase to 173 million tons, and by 2024 to 180 million tons[24].

The total length of railway lines in the regions of Eastern Siberia and the Far East is 17.3 thousand km, or 20% of the length of Russian railways[25]. The railway network is concentrated mainly in the Irkutsk Region, Zabaykalsky and Krasnoyarsk Territories, as well as in the southern zone of the Far East - in Primorsky, Khabarovsk Territories, Amur and Sakhalin regions. In a number of regions (Tyva Republic, Magadan Region, Kamchatka Territory, Chukotka Autonomous Okrug) there is no railway communication at all[26]. The average density of railway tracks is 1.7 km per 1 thousand square meters. km of territory, which is significantly inferior to the average Russian indicator - 5 km per 1 thousand sq. km of territory.

Since 2019, in the context of growing coal shipments in the direction of the seaports of the Pacific coast, shippers have faced the problem of a lack of railway infrastructure on the eastern road range

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[22] https://www.oteko.ru/press/news/gk_-oteko-_i_ggmk_-evraz-_podpisali_dogovor_o_pere/
[23] Source: Railway statistics
[24] https://neftegaz.ru/news/coal/774050-rzhd-vostochnyy-poligon-ne-rezinovyy-kompaniya-prizyvaet-proyavlyat-bolshe-otvetstvennosti-pri-organ/
[25] https://fedstat.ru/indicator/60319
[26] https://cargo.rzd.ru/ru/9787/page/103290?id=11175#main-header

(Bardal A.B., 2019). The loading of railways in the east direction was close to a critical level, about half of the sections were loaded by more than 95%. Key bottlenecks: the western section of the BAM (Severomuysky Tunnel, Taksimo - Tynda sections), segments of the Trans-Siberian Railway (Taishet - Petrovsky Zavod, Chernyshevsk - Khabarovsk). At the same time, the loading of the eastern landfill is also affected by passenger traffic, in respect of which the carrier has established priority over freight traffic.

To address the issues that have arisen, the Rules for Non-Discriminatory Access of Carriers to the Railway Transport Infrastructure have been changed. Made additions determine the following order of priority for providing transportation in areas with limited infrastructure[27]. In 2022, the regulations were temporarily lifted as transporting goods with higher margins, such as containers and lumber, proved to be more financially beneficial for Russian Railways than coal. Consequently, the railway's capacity to export coal via the Eastern Road was curtailed considerably below the targeted volume set by the Russian President's directive.

Southern Sea Route

Most often, the NSR is compared with the traditional sea route through the Suez Canal, or, as it is also called, the Southern Sea Route.

The Suez Canal literature was initially published in 1956, evaluating the financial and economic implications of the canal (Baer, 1956). By utilizing Queueing Theory, Griffiths (1995) analyzed waiting times and queues at the canal entrance to increase ship throughput and decrease waiting delays. This approach provided a comprehensive understanding of transportation operations within the canal using the QT model (Laih, Tsai and Chen, 2014). To approach the canal from a supply chain management perspective, Sun and Laih (2021) published a study on optimal pricing for the Suez Canal. They proposed a steady-state model that considers a timetable and toll scheme, accounting for the extension of the canal, to minimize queues at the entrance. In their study, Gast and colleagues (2021) created a model that forecasts the duration of wait time for vessels in a queue before resuming their journey, as well as the time at which the entire queue disperses and a new service cycle begins with normal behavior.

The Suez Canal provides approximately 12% of world trade, about 50 ships pass through it every day[28]. Lloyd's List estimates that it costs about $5.1 billion a day to move goods westward across the

[27] http://docs.cntd.ru/document/564979863
[28] https://logirus.ru/articles/solution/esli_ne_suets-_to_kto_zhe.html

Suez. Eastbound traffic on this artery is about $4.5 billion. About 19,000 ships passed through the canal during 2021, an average of 51.5 ships per day, according to the Suez Canal Authority. For comparison: in 2020, this figure was about 18,900 ships. At the same time, the revenue of the canal administration for the 2020/21 financial year amounted to $5.72 billion. The cost of passage through Suez depends on the weight of the cargo, the draft of the vessel, the height of the cargo on the deck, the date of application and other factors. In addition, in 2021, the administration of the Suez Canal decided to raise the rates of fees for passing dry cargo ships and LNG tankers by 5%. On average, the fee ranges from $6 to $12 per ton. Thus, the total cost of passage of a heavy-duty vessel can reach from $160,000 to $1 million. As advantages of the southern sea route, it is worth noting stable trade relations, the presence of large ports along the route, developed infrastructure (Larchenko, 2018). Also, this route is preferable for transporting dangerous goods such as oil products, gas condensate, liquefied natural gas, etc.

Northern Sea Route

The Northern Sea Route is the shortest sea route between the European part of Russia and the Far East. It is defined by the legislation of the Russian Federation as "the historically established national unified transport communication of Russia in the Arctic". The Northern Sea Route passes through the seas of the Arctic Ocean (Kara, Laptev, East Siberian and Chukchi). It should be also noted that the NSR does not have a fixed route.

The route may change depending on weather and ice conditions. The length of the Northern Sea Route from the Kara Gates to Cape Dezhnev is, depending on the route, up to 3000 nautical miles. The water area of the Northern Sea Route is understood as the water area adjacent to the northern coast of the Russian Federation, covering the internal sea waters, the territorial sea, the contiguous zone and the exclusive economic zone of the Russian Federation and bounded from the east by the demarcation line of maritime spaces with the United States and the parallel of Cape Dezhnev in the Bering Strait, from the west by the meridian of Cape Zhelaniya to the Novaya Zemlya archipelago, the eastern coastline of the Novaya Zemlya archipelago and the western borders of the straits Matochkin Shar, Kara Gate, Yugorsky Shar.

The Northern Sea Route is part of the Northern Transport Corridor, which starts from the port of Murmansk and ends at Cape Dezhnev. The largest ports of the Northern Transport Corridor are Murmansk and Arkhangelsk, and in the NSR zone - Igarka, Dudinka, Dikson, Tiksi and Pevek.

Until the end of the first decade of the 21st century, the main purpose of the NSR was to provide food and other goods to the inhabitants of the Arctic regions, as well as to transport minerals from the Arctic deposits[29].

According to some experts, transportation through the Northern Sea Route can be faster and cheaper than through the Suez Canal, and the Russian government has repeatedly emphasized the importance of developing this direction[30]. At the same time, transportation along the Northern Sea Route comes with a number of risks, and because of these risks, some experts argue that the Northern Sea Route "will never be an alternative route"[31] and the programs for the development of the Northern Sea Route are considered as “nothing more than politics”. Thus, the purpose of this paragraph is to inspect the possible benefits of using the Northern Sea Route revealed in the academic literature, as well as to review the potential risks for shippers.

The indisputable advantage of the Northern Sea Route compared to the Southern one is the length of the route - 5,600 kilometers and about 23,000 kilometers, respectively. In addition, the Southern Corridor provides for the passage of cargo ships through a bottleneck - the Suez Canal, which is 160 kilometers long, about 350 meters wide and about 20 meters deep. Such a length noticeably increases the time of delivery of goods, the cost of escorting and guarding ships, and its small width forces the company's ships to be overloaded with smaller ones leased at the port. In this regard, more and more attention, both among academicians and among management practitioners, is being drawn to an alternative sea corridor - the Northern Sea Route, which is quite capable of being a competitor to the Southern Sea Route[32].

There are several research papers in the literature investigating the uncertainty along the northern sea route. According to a survey conducted by Lasserre in 2014, a total of 26 models assessing the relevance of the Northern Sea Route (NSR) were published between 1991 and 2013. Lasserre notes that it is challenging to establish credible parameters for creating a model that could evaluate the profitability of Arctic shipping and compare findings across various studies. Fuel costs are the most significant single factor out of all the parameters considered, with 17 models assuming the same fuel consumption rate for both the NSR and Southern Sea Route (SCR) and employing IFO380 as the

[29] https://energy.skolkovo.ru/downloads/documents/SEneC/Research/SKOLKOVO_EneC_RU_Arctic_Vol3.pdf
[30] https://www.vedomosti.ru/business/articles/2022/08/05/934655-dorozhnuyu-kartu-sevmorputi
[31] https://ria.ru/20180910/1528172961.html
[32] Guranova A.A. (2019) Logisticheskie preimuschestva Severnogo morskogo puti [Logistics advantages of the Northern sea route]. Ekonomicheskie otnosheniya. 9. (1). – 169-176. doi: 10.18334/eo.9.1.39636

primary fuel type. However, Lasserre indicates that this assumption may not be suitable for very cold temperatures. Models selected different comparison speeds for year-round navigation, ranging from 7 to 15 knots. Capital cost premiums are determined by the class and range of ice-class ships, with 17 models estimating premiums between +1% and +120%. While eight models assume identical crew cost structures, the remaining seven indicated a necessity for well-trained crews. Underwriters for insurance premiums estimated a wide range of estimates, with three models assuming zero insurance premiums and others estimating risk premiums between 50% and 100%. Of the seven Arctic bulk shipping models Lasserre reviewed, three were profitable, and four were not.

A combination of professional presentations, reports, and academic studies make up these cost models, which suggest that it is not feasible to use the Northern Sea Route (NSR) for bulk shipping. Mulherin et al. (1996) argue that the limited carrying capacity of ships on the NSR, at only around 25% compared to those on traditional trade routes, is a significant obstacle. This eliminates any distance advantage the NSR may have. Paterson (2011) notes that summer fog still poses challenges to navigation and requires expert training. Kamesaki et al. (1999) and Kitagawa (2001) come to similar conclusions that the main issues with NSR shipping are rooted in Russia, including legal problems, taxation and tariffs, and exorbitant icebreaker tariffs. As a result, the obstacles and costs make NSR shipping impractical.

As for more recent studies, there are several papers as well. Despite the advancements in science and technology, Arctic maritime activity remains a hazardous undertaking due to various unpredictable factors such as sea ice, low temperatures, darkness, remoteness, and challenging weather conditions. The lack of relevant crew experience also adds to the uncertainty. One of the most perilous hazards related to ship-ice interaction is the possibility of a ship becoming beset in ice, which means it is surrounded by ice and unable to move under its own power (Sheng Xu et. al, 2022). This can cause significant operational disruptions and delays, and in the worst-case scenario, it can lead to structural damage and endanger the safety of the ship by exposing it to severe ice loading or causing it to drift towards shallow water. These uncertainties and risks associated with besetting are a significant challenge for commercial Arctic shipping. (Guy, 2006; Marken et al., 2015).

The research conducted by Sheng Xu et. al in 2022 presents the development of a Bayesian Network model aimed at predicting the likelihood of ships becoming stuck in ice during a convoy operation along the Northern Sea Route (NSR). The model concentrates on the initial assisted ship and draws on expert input for its formulation. The research identifies four potential scenarios that may lead to the initial assisted ship encountering trouble. The study finds that the three most vital factors that contribute to a ship being trapped in ice are the level of ice concentration, the distance between the icebreaker and the ship, and the navigational experience.

It is also undeniable that the movement in the ice significantly slows down the movement of ships. During drifting ice seasons, ship speed is reduced to 14 knots (from 20–24 knots in good weather). Therefore, Western companies avoid transporting goods during this period, either significantly overestimate the insurance for their transportation, or do not use this route at all, preferring the Southern Sea Route. According to the publication by Tseng and Pilche (2017), uncertainties exist about when the NSR will become free of ice, the exact travel times around ice, and which routes will be available for all types of ships. In addition, there is a lack of clarity about the risks associated with supply chain transport if containers benefit from the NSR, and numerous unknown factors must be in place for the NSR to be successful, including the implementation of a polar code, enhanced infrastructure, and political and legal agreements regarding tolls.

However, despite the uncertainties encountered along the Northern Sea Route, some studies support the commercial use of the Northern Sea Route. For example, Cho (2012) conducted a comparison for an oil tanker sailing from Kirkeness or Murmansk to Pusan at 16 kts, which concluded that the NSR could provide a savings of 36% in terms of costs and CO_2 emissions. However, these results were mostly based on distance savings. In a more comprehensive analysis performed by Schøyen and Brathen (2011) comparing the deployment of Handymax or Capesize vessels between Norway and Eastern Asia with the NSR, SCR or Cape of Good Hope route, the authors concluded that the NSR is both economically viable and environmentally sustainable. Falck (2012) from Tschudi Shipping Company AS also concluded that sailing from Kirkeness to Yokohama for a 40,000 dwt vessel via the NSR could result in significant cost and time savings.

Thus, the analysis (Solvang et.al., 2018) highlights that the commercialization of the NSR can benefit the Scandinavian economy (e.g. increase in GDP, job creation) and reveals the advantages of Scandinavian ports (e.g. flexibility, hinterland, etc.) compared to other ports in the North Europe, which potentially use the NSR as an opportunity.

It is important to note that there are still uncertainties and challenges associated with the NSR such as operational challenges, taxation and tariff, speed and fuel prices, which are key factors to assess the viability of the NSR.

However, there is still a research gap in the bulk shipping sector exploring how these uncertainties are included in the calculations, which this master thesis aims to address.

Chapter Conclusion

In this chapter, an overview of the Russian coal export industry was made. Russia is one of the key coal producers on the world market, and most of the export Russian coal is shipped to Asian countries as the region with the highest demand in the world (taking up to 70% of coal imports).

More than half of the exported coal is mined in the Kuzbass basin, and the main ways of shipping coal include the ports of the Far Eastern basin, the Western (which includes the Arctic and Baltic basins) and the Southern basin.

Also, this chapter highlighted the key problems that coal exporting companies have faced in recent years: first of all, this is a lack of carrying capacity towards the Far Eastern ports.

One of the promising routes for transporting coal is the Northern Sea Route. However, at the moment, it is mostly used by companies that deliver to the Northern parts of the Russian Federation, where it is impossible to reach by other means (for example, a plant in such distant regions as Norilsk), and the issue of commercializing the route has not yet been resolved.

Articles exploring the prospects of the Northern Sea Route were considered. Despite the abundance of articles in this area, there is no general consensus on this issue. However, many researchers emphasize that the key factor hindering the commercialization of the route is the uncertainties encountered along the Northern Sea Route. At the same time, there are no studies that would estimate the cost of transportation along the Northern Sea Route, taking into account the uncertainties in transportation issues. Thus, this study aims to close this research gap.

Chapter 3. Research Methodology

In the current research, two interrelated models need to be described: the transportation cost model and the route selection model. The first part of this section describes the supply chain cost model, which consists of the rail transportation costs, transshipment costs and freight costs. The cost of transporting the goods from the port of the consumer to the place of use by the consumer is going to be neglected due to the fact that there are many end users of Russian coal in China, and the cargo can be sent to various directions in China, due to the fact that there are many end users of Russian coal in China, and the cargo can be sent to various directions in China, and for each of which there will be a different cost of delivery from the port of China to the place of consumption.

The second part of this section describes the mathematical statement of the problem of choosing a route according to a number of criteria. I'm going to take into consideration such criteria as minimizing cost for a given level of risk, minimizing risk for a given level of cost, a criterion that considers both risk and return and the VaR criterion.

At the end of this chapter, a model for estimating a real option for switching from the current route to the route of the Northern Sea Route is proposed.

Transportation costs model

In general, the function of transportation costs in our case consists of three components: the cost of transportation by rail, the cost of loading and unloading operations in the port and the cost of transportation by sea:

$$Transportation\ costs_i = \left(freight\ quote_i * days_{freight} + transshipment\ tariff_i * days_{transshipment} + railway\ tariff_i * days_{railway}\right) * Q_{possible\_i}$$

Where

- $freight\ rate_i$ – freight price (transportation of 1 ton of cargo on a ship) in direction i (in dollars per 1 ton) for 1 day
- $days_{freight}$ – number of days required to transport cargo by sea
- $transshipment\ tariff_i$ – the cost of transshipment of 1 ton of cargo in the port in direction i (in dollars per 1 ton) for 1 day
- $days_{transshipmment}$ – number of days required for loading and unloading operations in the port

- $railway\ tariff_i$ – cost of transporting 1 ton of cargo by rail in direction i (in dollars per 1 ton) for 1 day
- $days_{railway}$ – the number of days required to transport goods by rail in the direction i
- $Q_{possible\_i}$- cargo volume (in tons)

Estimating costs for a route for which there is a transportation market is a rather trivial task: it is enough to find all the components of the cost function in periodicals and forecast the data for the appropriate period. However, such a transportation market with real market quotations exists only for routes through the Far East Road and through the Suez Canal.

The Northern Sea Route, despite its current use by some companies (for example, Norilsk Nickel uses this route on a regular basis to transport its cargo from Murmansk to the port of Dudinka[33], but these shipments are carried out mostly by their own ships, not chartered ones), represents is still a promising direction of transportation, for which it is impossible to determine the market value of freight rates. Thus, a cost-based approach, taking into account the operating margin, will be used to estimate the cost of transportation by sea through the Northern Sea Route. The similar approach was proposed by Gleb&Jin (2021).

Since transportation through the Northern Sea Route in terms of estimating the cost of transportation along it differs only in the cost of transportation by sea, we present the formula by which the freight rate will be calculated for this specific route:

$$freight\ quote_{north} = \frac{\text{OPEX} * operaing\ margin}{ton}$$

$$OPEX = fuel\ price_{wo\ icb_{sup}} * days_{wo\ icbsup} + fuel\ price_{w\ icb_{sup}} * t * days_{w\ icbsup} + admin\ costs + serv\ costs + north\ route\ ins\ costs + icebsup\ costs * days_{w\ icbsup}$$

Where

- $fuel\ price_{wo\ icb\_sup}$ - fuel price without icebreaking assistance, considered as standard fuel price * Consumption intensity without icebreaking assistance (because without ice, a dry cargo ship has a different speed, and at different speeds, different fuel consumption intensity)
- $days\ w\ icb_{sup}$ - the number of days during which icebreaking assistance is needed.
- $days\ wo\ icb_{sup}$ – the number of days during which icebreaking assistance is not needed

[33] https://portnews.ru/news/332651/

- $admin\ costs + serv\ costs + north\ route\ ins\ costs$ - Administrative costs, maintenance costs, ship insurance in ice
- $operating\ margin$ - carrier margin required to match shipping costs with alternative routes

In this study, it was assumed that the icebreaker is required for ships in winter navigation and is not required in summer. Also, as mentioned in paragraph 3.2.2, data on the passage of vessels for the Arctic class Arc 4 and higher were taken for analysis, which, in accordance with the Rules for navigation along the Northern Sea Route[34], is not mandatory to be accompanied by an icebreaker.

Route choice model

This section describes the problem statement of distribution of volumes of exported coal. In the considered problem, goods are transported between a single supplier and a single consumer. However, there are 4 ways to carry out the transportation.

Figure 4. Map with transportation routes. Source: constructed by the author

Further, for the convenience of setting up a mathematical model, we will use the following indices: 1 - Strait route through the port of Vostochny, 2 - route through the port of Murmansk and the Bering, 3 - route through the port of Murmansk and the Suez Canal, 4 - route through the port of Taman. In this case, routes 3 and 4 are considered independent despite the fact that there are matching edges on the transport scheme inside the mentioned routes.

[34] http://www.nsra.ru/files/fileslist/137-ru893-2020.pdf

Also, navigation in the eastern sector of the NSR in winter is impossible without icebreaking assistance for vessels of any type of the Arctic class due to weather conditions: the ice thickness reaches 3 m[35]. Thus, for the purposes of modeling, it was decided to divide the Northern Sea Route into 2 different routes: northern sea route in summer and winter. According to the Rules of navigation along the Northern Sea Route[36], the summer navigation period is from July 1 to November 15, and, accordingly, the winter navigation period is from November 16 to the end of June.

It is proposed to consider two levels of problem statement, where each subsequent level serves as a development of the previous one:

1) Deterministic statement of the problem. In this formulation, transportation costs are considered constant and the trivial problem of finding the optimal way to send cargo while minimizing costs is solved
2) Stochastic statement of the problem. This formulation takes into account that transportation costs are a random variable due to unpredictable transportation conditions and risks. The mathematical statement of the problem is taken from the problem of the Markowitz statement, which optimizes the investment portfolio of assets.

Deterministic model

It is required to determine such a transportation plan, that is, the values of x_1, x_2, x_3, x_4, x_5 in which the objective function

$$Q = \sum_{i=1}^{5} c_i x_i \to min$$

under conditions

$x_i \geq 0, i = \overline{1,5},$

$x_i \leq L_i, i = \overline{1,5}$

Finding a solution to this problem is possible using the simplex method (Dantzig, 1963).

As it was mentioned in second chapter, according to several articles, transportation via the Northern Sea Route is cheaper than via the Southern Sea Route (Schøyen&Bråthen, 2011; Zeng et al, 2019;

[35] https://www.vedomosti.ru/business/articles/2021/11/19/896771-pochti-dva-desyatka-sudov-zastryali-vo-ldah-na-sevmorputi
[36] http://www.nsra.ru/files/fileslist/137-ru893-2020.pdf

Furuichi&Otsuka, 2014; Larchenko et al, 2018). Also, in reality, goods are transported through the Far Eastern Road. Thus, the following research proposition can be stated:

Research Proposition #1

In the deterministic model, according to the criterion of minimizing the overall logistics costs, all cargo that cannot be sent through the Far East Road must be sent through the Northern Sea Route (both in winter and in summer).

Stochastic model

A distinctive feature of this problem statement from the previous one is the assumption that, due to risks associated with the transportation through different routes, the cost of using any of the routes may turn out to be a random variable.

The method proposed in this section takes advantage of a well-studied method called efficient frontier (Markowitz, 1959; Murty, 1988) which has already been implemented in the context of portfolio selection. Sadjadi (2007) justified that this method has a strong implementation in the field of transportation.

General problem statement

We will set x_1, x_2, x_3, x_4, $x_5$as the shares of the cargo flow in the corresponding directions

$$x_1 + x_2 + x_3 + x_4 + x_5 = 1.$$

We will call the set x_1, x_2, x_3, x_4, x_5 as "transport portfolio".

In contrast to the model of the optimal investment portfolio, in the transport problem under consideration, the costs necessary for the implementation of transportation are calculated.

If route i is chosen, then the (random) costs are equal to $\tilde{c}_i$ per unit of cargo. This random variable will be characterized by the parameters m_i- the expectation of costs, and V_i- the variance of costs.

We assume that the costs for any route are independent of the costs for other routes. Then the cost covariances, as random variables, are equal to zero.

Then the total cost of transporting a unit of cargo is a random variable equal to:

$$\tilde{C} = x_1\tilde{c}_1 + x_2\tilde{c}_2 + x_3\tilde{c}_3 + x_4\tilde{c}_4 + x_5\tilde{c}_5,$$

the mathematical expectation of which is equal to:

$$\bar{C} = x_1 m_1 + x_2 m_2 + x_3 m_3 + x_4 m_4 + x_5 m_5,$$

where m_1, m_2, m_3, m_4, m_5 are the mathematical expectations of the costs of transport portfolio elements.

The portfolio variance

$$V = x_1^2 V_1 + x_2^2 V_2 + x_3^2 V_3 + x_4^2 V_4 + x_5^2 V_5,$$

here V_i is the variance of costs in the i -th direction.

The risk of a "transport portfolio" is determined by the standard deviation of costs, which is equal to the square root of the portfolio's variance.

In the following parts of this section, we consider the classical formulation of the Markowitz portfolio optimization problem applied to a portfolio of transportation routes. To do this, we consider the problem from the standpoint of minimizing transportation costs at an acceptable level of risk and minimizing risk at an acceptable level of costs. Also, it is proposed to expand the Sadjadi (2007) model with the VaR criterion (Okulov, 2019).

Minimization of costs with an acceptable cost uncertainty

Find such x_i, that

$$\bar{C} = x_1 m_1 + x_2 m_2 + x_3 m_3 + x_4 m_4 + x_5 m_5 \to min$$

under the conditions that

$\sqrt{V} = V_{acceptable}$,

$x_1 + x_2 + x_3 + x_4 + x_5 = 1$,

$A x_i \leq L_{i\ capacity}$,

Where

A – total cargo volume transported,

$L_{i\ capacity}$ – route capacity,

Minimizing the Uncertainty of Costs for a Given Value of Costs

Find such x_i, that

$$\sqrt{V} = \sqrt{x_1^2 V_1 + x_2^2 V_2 + x_3^2 V_3 + x_4^2 V_4 + x_5^2 V_5} \to min$$

under the conditions that

$\bar{C} = C_{acceptable}$,

$x_1 + x_2 + x_3 + x_4 + x_5 = 1$,

$Ax_i \leq L_{i\ capacity}$,

Where

A – total cargo volume transported,

$L_{i\ capacity}$ – route capacity.

Both tasks are equivalent. The solution can be constructed using the Lagrange multiplier method.

The result of solving problems stated is a closed area on the “costs-uncertainty” graph similar to the Markowitz umbrella.

This model includes 2 groups of sources of uncertainty: price factors (coming from the price components included in the cost of each of the routes) and non-price factors (expressed in the number of days required for delivery along each of the routes).

According to experts, one of the main factors of uncertainty on the Northern Sea Route is unpredictable ice conditions. Even if the meteorological service assumes that the situation will be easy in the near future, the next day things can become much more complicated. This uncertainty is expressed in the expected number of days required for the delivery of cargo along the Northern Sea Route.

The price factors of uncertainty are the volatility of freight rates[37], transshipment rates, and railcar transportation rates. However, some experts argue that these price uncertainties along different routes are caused by the same factors[38] (such as the price of coal, the general economic situation in the world[39], etc.) Price and non-price uncertainties in the model are proposed to be modeled separately.

Moreover, as mentioned above, navigation in the eastern sector of the NSR in winter is impossible without icebreaking assistance for ships of any type of the Arctic class due to weather conditions, which slows down the speed of passage through the northern sea route. Moreover, ships can get stuck in the ice, not having time to wait for the help of the icebreaker. These factors lead to the assumption that freight rates are more volatile and expensive in winter than in summer.

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[37] https://infranews.ru/logistika/59273-dolgosrochnye-fraxtovye-stavki-za-god-pochti-udvoilis-xeneta/

[38] https://www.apk-inform.com/ru/exclusive/opinion/1524805

[39] https://www.dp.ru/a/2022/02/09/Relsi_kak_alternativa

Thus, the following research proposition can be formulated:

Research Proposition #2

2(a). The expected cost of transporting cargo in winter on the NSR is higher than the expected cost of transporting cargo in summer.

2(b). The volatility of shipping costs in winter on the NSR is greater than the volatility of shipping costs in summer

2(c). Most of the cargo traffic must be sent to the Far East and the Northern Sea Route in summer in accordance to minimization of costs criterion.

2(d). In accordance with the criterion of minimizing risks at a given level of costs, the cargo should not be sent along the northern sea route both in summer and in winter

Route choice criteria

Previous sector already described the classical criteria for choosing an appropriate portfolio of routes: the risk minimization criterion for a given cost and the cost minimization criterion for an accepted level of risk. These two criteria represent two polarities: if a company is careful to avoid risk, but is willing to pay any money for delivery, it should choose a portfolio with a set of routes that can be the most expensive, but also the most risk-free. At the same time, if a company wants to reduce costs in any way, but at the same time is ready to take risks, it makes a decision for itself to send cargo along a set of routes that is characterized by minimal costs but maximum risk. These two sets of routes will be at opposite ends of the effective Markowitz boundary.

In this section, two more decision criteria for choosing the optimal portfolio are considered. The first criterion is the "mean-variance" criterion, which takes into account both the costs of the portfolio and its risks. The second criterion is the VAR criterion, which is suitable for those decision makers who want to understand that in the worst case, for a given level of probability (typically 95%), their losses will not be greater than the number that this criterion shows when choosing this path.

Mean-variance criterion

The "mean-variance" criterion prescribes in conditions of uncertainty to make a choice, focusing not only on the expected result of the alternative, but also on the spread (dispersion) of possible results in different states of nature. That is, this criterion takes into account the riskiness of alternatives (Okulov, 2019).

To select a route, it can be assumed that the subject must minimize some objective function Y, which is often considered in practice as the ratio of the expected result to the standard deviation of the results:

$$Y = \frac{E[\widetilde{X}]}{\sqrt{D[\widetilde{X}]}} \to min$$

It was shown in a number of academic papers that despite the simplicity of this criterion, it is a powerful decision tool in portfolio optimization (Kalayci, Ertenlice and Akbay, 2019).

In the context of the portfolio task being solved, taking into account the risks of transportation along the Northern Sea Route described in the previous chapter and the attention paid to this route within the strategic development of the Russian Federation, the following Proposition can be stated:

Research Proposition #3

According to the "mean-variance" criterion, the optimal set of routes includes the transportation through the Northern Sea Route

Value at Risk (VAR) criterion

From a mathematical point of view, risk is treated as uncertainty, but in practice, people and companies intuitively perceive risk as an opportunity (danger) that the outcome of the situation will turn out to be critically bad. The J.P.Morgan bank's analysts in 1996 proposed a measure to associate the worst result with the level of risk, which in reality will be exceeded with a high (predetermined probability).

With this method of risk assessment, a confidence level of probability is first set, and then the worst result is determined, which will be exceeded with a given probability. The calculated result becomes a measure of the risk of the game: the worse the result, the riskier the situation. Using this approach to risk assessment, the subject agrees that in reality even worse outcomes are possible in this situation, but their probability is so small that such outcomes are not worth paying attention to (Okulov, 2019).

Formalization of the problem for finding the value of VAR in the context of a portfolio of routes is as follows:

For a random variable $\sqrt{V}$, it is possible to calculate the quantile of the probability distribution at a given probability level α: v_α. Then the problem acquires the meaning that with a given probability α the transport costs will be less than v_α.

Find such x_i, that

$v_\alpha \rightarrow min$

under the conditions that

$\bar{C} = C_{acceptable}$,

$x_1 + x_2 + x_3 + x_4 + x_5 = 1$,

$Ax_i \leq L_{i\ capacity}$,

Where

A – total cargo volume transported,

$L_{i\ capacity}$ – route capacity,

To find v_α, it is necessary to solve the equation with the parameter:

$$\int_{-\infty}^{v_\alpha} f(x)dx = \alpha,$$

where $f(x)$ is the density of the assumed distribution law.

Also, a non-parametric method called historical simulation is often used to calculate VaR. This method approximates using the empirical distribution of data and identifies the quantile of the empirical distribution as VaR. Different sample sizes can be used to calculate the empirical distribution of financial returns. Down (2002) has documented the advantages and disadvantages of the historical simulation approach. The main advantages are simplicity and the ability to include unusual features such as big tails and asymmetry in financial observations. However, the main potential weakness of this approach is that its results are highly dependent on the underlying dataset. In cases where the data set is very quiet, the historical simulation method tends to underestimate risk, while during periods of high volatility it tends to overestimate risk. Additionally, this approach may not reflect important timely events, such as the emergence of risks arising from sudden market turbulence.

Research Proposition #4

According to the VAR criterion, the optimal route will be the one in which there is a share of transportation along the Northern Sea Route.

Real Option valuation model

As already mentioned, the Northern Sea Route is a promising route for shipping goods from Russia to Asian markets. But it is still not a commercially developed route for various reasons: lack of fleet, lack of port infrastructure, but most importantly - unpredictable weather conditions that lead to ships getting stuck in the ice. However, Russia is now actively developing the northern sea route: nuclear icebreakers are being built, and investments are being made in port facilities.

At the same time, the company must "keep abreast" and take care in advance to be able to switch to a route that in the future may become more economically viable than all existing ones. In order to be able to switch to this promising route after some time, the company must invest now.

In order to understand how much a company should invest now, it is proposed to consider this problem as a problem of real options. In particular, it is proposed to consider an option for the exchange of assets: by assets we mean the exchange of the current route (one of the existing ones) for the route along the Northern Sea Route.

Consider a European option to change an asset of value U at time T and receive an asset of value V instead.

The formula for calculating the value of this option was first proposed by Margabe[40].

In its original form, the formula looks like this: it is supposed that the prices of assets U and V are described by the law of geometric Brownian motion with volatilities σ_U and σ_V. Let us further assume that the coefficient of instantaneous correlation between the asset prices of U and V is equal to ρ, and the return on assets is equal to q_u and q_v, respectively. Then the value of the option at time zero is

$$V_0 e^{-q_v T} N(d_1) - U_0 e^{-q_u T} N(d_2),$$

where

$$d_1 = \frac{\ln\left(\frac{V_0}{U_0}\right) + \left(q_u - q_v + \frac{\hat{\sigma}^2}{2}\right)T}{\hat{\sigma}\sqrt{T}},$$

$$d_2 = d_1 - \hat{\sigma}T,$$

$$\hat{\sigma} = \sqrt{\sigma_U^2 + \sigma_V^2 - 2\rho\sigma_U\sigma_V},$$

and U_0 and V_0 are the values of assets U and V at the initial moment.

---

[40] Margabe W. The Value of an Option to Exchange One Asset for Another // Journal of Finance, 33 (March 1978). – p.177-186

It should be noted that the value of this option does not depend on the interest rate. This is because the rate of price growth of both assets in risk-neutral conditions, which increases with an increase in the rate, is fully offset by an increase in the discount rate (Hull, 2014).

Trigeorgis (2005) has shown that this model is appropriate for valuing a switch option, which is the option in this study[41].

To solve the problem of estimating the option to switch from the current route to the Northern Sea Route, we will take the following changes: we will assume that the asset values enter the model with negative signs, that is, -U is the cost of transportation along one of the existing routes, and -V is the cost of transportation along the Northern Sea Route. In this paper, it is supposed to consider separately transportation along the Northern Sea Route in summer and in winter.

Also, since the concept of return on assets is not applicable in the case being solved, it was decided to assume returns equal to zero.

The volatility of costs for transport routes is estimated according to the model proposed in the next paragraph. Also, the correlation coefficient between routes is supposed to be taken from the calculation of the correlation coefficient for compiling the Markowitz portfolio. The detailed results of the assessment and a description of the approaches to this assessment are described in Chapter 4.

Thus, the assessment of this option makes it possible to understand how much it is possible to invest in the development of the Northern Sea Route in order to be able to switch to it from one of the current routes in T years.

Data gathering and forecasting

Data gathering sources

All sources of information for estimating the parameters of the models above are presented in the following table

Table 1 Models' parameters and data sources. Source: constructed by the author

Model	Parameter	Data Source
1.1. Financial model of transportation through Far East Road	$freight\ rate$	Argus database
	$days_{freight}$	AXS Dry ship call statistics 2015-2021
	$transshipment\ tariff_i$	Argus Russian Coal, monthly prices 2015-2021

[41] Lenos Trigeorgis (2005): MAKING USE OF REAL OPTIONS SIMPLE: AN OVERVIEW AND APPLICATIONS IN FLEXIBLE/MODULAR DECISION MAKING, The Engineering Economist: A Journal Devoted to the Problems of Capital Investment, 50:1, 25-53

	$days_{transshipmment}$	Industry Reports
	$railway\ tariff_i$	Pro-Vagon database
	$days_{railway}$	Russian Railway statistics
1.2.Financial model of transportation through South Sea Route	$freight\ rate$	Argus Russian Coal, Argus Freight
	$days_{freight}$	AXS Dry ship call statistics 2015-2021
	$transshipment\ tariff_i$	Argus Russian Coal
	$days_{transshipmment}$	Industry Reports
	$railway\ tariff_i$	Pro-Vagon database
	$days_{railway}$	Russian Railway statistics, yearly
1.3.Financial model of transportation through North Sea Route	$freight\ rate$	Calculations based on formula described in Research model chapter, parameters described below
	$days_{freight}$	The Northen Sea Route Administration ship call statistics 2015-2021, Clarksons Ship Info Database
	$transshipment\ tariff_i$	Argus Russian Coal
	$days_{transshipmment}$	Industry Reports
	$railway\ tariff_i$	Pro-Vagon database
	$days_{railway}$	Russian Railway statistics
2.1. Deterministic Route Choice model	L_i	Industry Reports, author's assumptions
2.2. Stochastic Route Choice model	$Variance$	1. Calculated based on $days_{freight}$, taking into account the distribution law of the random variable 2. Calculated based on prices
	$V_{acceptable}$	Industry Reports, author's assumptions
	$L_{i\ capacity}$	
	$C_{acceptable}$	

To estimate the freight rate along the Northern Sea Route, data are taken from the following sources:

Table 2.Models' parameters and data sources. Source: constructed by the author

Parameter of the Northern Sea Route costs calculation	**Subparameter**	**Data Source**
$freight\ rate$	$fuel\ price$	Statista (VLSFO)
	$days\ with\ icebreaker$	The Northen Sea Route Administration ship call statistics 2015-2021
	$admin\ costs$	Drewry Ship Operating Costs, 2021/22 Annual Review and Forecast
	$serving\ costs$	

	$north\ route\ ins\ costs$	The Northen Sea Route Administration

Data description

Freight rates for traditional routes of exporting Russian coal

For analysis, data was taken for ships with a loading volume (deadweight) of 100-110 thousand tons, since coal is carried over long distances by large ships due to economies of scale (and coal is a low-margin cargo, so it is unprofitable to transport it in small batches[42]). Also, larger deadweight ships were not considered in the current study as they are unable to pass the Suez Canal[43]. A detailed description of the types of ships according to their deadweight is given in Appendix 2.

Monthly freight rates for transportation from Murmansk, Taman and Vanino ports from 2015 to 2022 are presented on Figure 5.

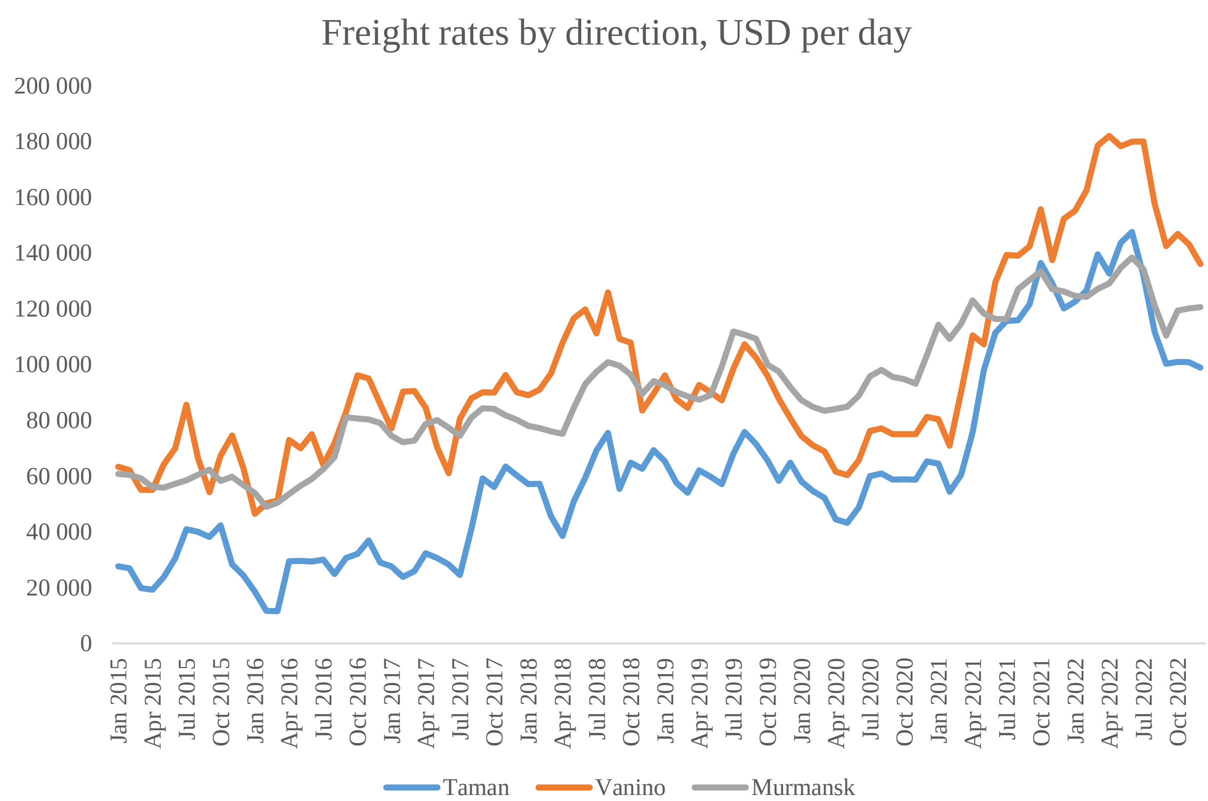

Figure 5. Freight rates by direction in 2015-2022. Source: Argus database

42 https://www.kommersant.ru/doc/5785312
43 https://morproekt.ru/materialy-po-tekhnologii/prilozheniya-i-spravochnye-materialy/klassifikatsiya-balkerov

Figure 2. Monthly freight rates of daily time charter for bulk post-panamax ships in 2015-2022. Source: Argus database

It can be seen that freight rates in different directions are highly correlated with each other, which is explained by the fact that the same factors influence the freight as a whole: the cost of fuel, demand in consumer markets, and the availability of a fleet capable of transporting cargo[44].

Freight rates estimation for Northern Sea of exporting Russian coal

As mentioned earlier, the freight rate for transportation through the Northern Sea Route is a calculated value, since there is still no market for transportation along this route. The initial data, on the basis of which the rate of transportation along the northern sea route was calculated, is shown in the Table 3.

Table 3.Parameters for NSR calculation. Source: constructed by the author

Parameter	**Data**	**Source**	**Comment**
Fuel consumption, tons per day	43.2	Drewry Ship Operating Costs, 2021/22 Annual Review and Forecast	Assumed constant for all periods
Fuel price	Volatile	Statista.com	Volatile, needed to be forecasted for 2023
Depreciation of a ship, th. USD per day	7.91 (in 2021)	Clarksons database	Assumed constant for all periods, but adjusted for annual dollar inflation. Within one year, the data is stable.
Crew expenses, th. USD per day	2.64 (in 2021)	Drewry Ship Operating Costs, 2021/22 Annual Review and Forecast	
Service expenses, th. USD per day	2.19 (in 2021)		
Administration expenses, th. USD per day	1.21 (in 2021)		
Operating Margin	29.7%	Sovcomflot 2022 Annual report	

[44] Metal Supply and Sales No. 11/2014, Issues 11-2014, p. 129

Thus, the total freight rate for transportation along the Northern Sea Route in the summer, assuming that this type of vessel does not require icebreaker escort in the summer, is as follows:

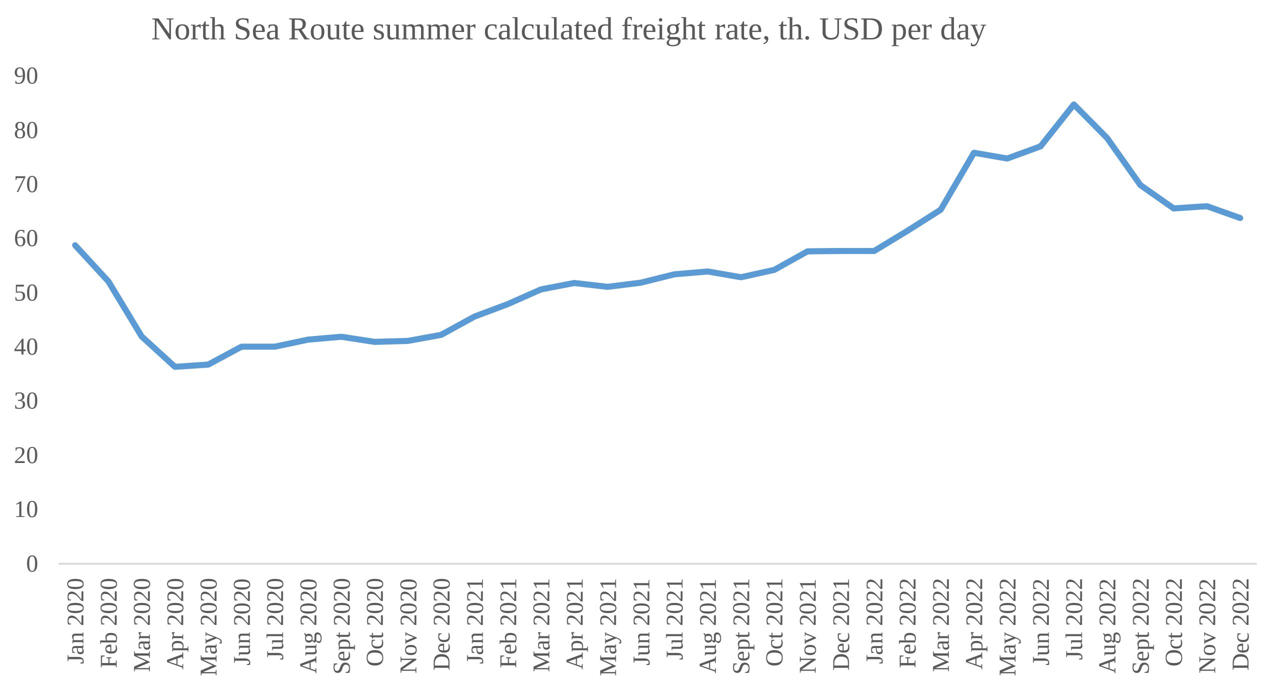

Figure 6. North Sea Route calculated freight rate for summer period. Source: constructed by the author

It should be noted that the freight rate along the Northern Sea Route is presented from the beginning of 2020, since the type of fuel. used in calculations, it began to be used by ships only from the end of 2019[45].

A similar table with assumptions is presented for the winter period of transportation along the northern sea route:

Table 4. Parametersfor NSR winter calculation. Source: constructed by the author

Parameter	**Data**	**Source**	**Comment**
Fuel consumption, tons per day	9.60	Drewry Ship Operating Costs, 2021/22 Annual Review and Forecast	Assumed constant for all periods

[45] Wang, D., Ding, R., Gong, Y., Wang, R., Wang, J., & Huang, X. (2020). Feasibility of the Northern Sea Route for oil shipping from the economic and environmental perspective and its influence on China's oil imports. Marine Policy, 118, 104006. https://doi.org/10.1016/j.marpol.2020.104006

Fuel price	Volatile	Statista.com	Volatile, needed to be forecasted for 2023
Depreciation of a ship, th. USD per day	35.91 (in 2021)	Clarksons database	Assumed constant for all periods, but adjusted for annual dollar inflation. Within one year, the data is stable.
Crew expenses, th. USD per day	2.77 (in 2021)	Drewry Ship Operating Costs, 2021/22 Annual Review and Forecast	
Service expenses, th. USD per day	2.42 (in 2021)		
Administration expenses, th. USD per day	1.29 (in 2021)		
Icebreaker assistance	37.7 (in 2021)	North Sea route site	
Operating Margin	29.7%	Sovcomflot 2022 Annual report	

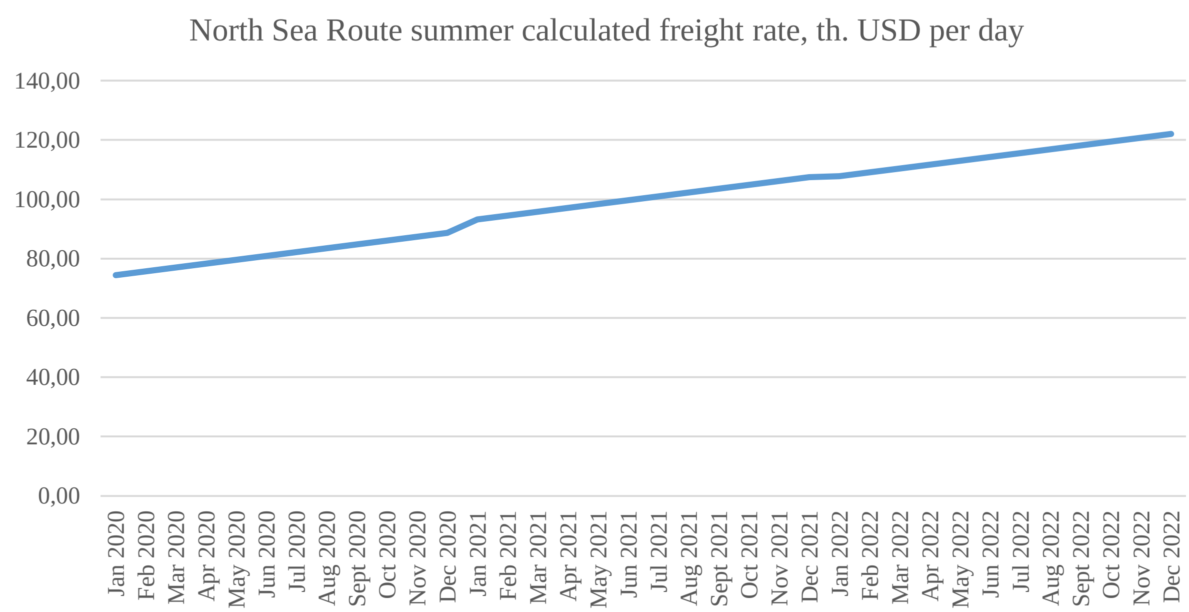

Figure 7. North Sea route summer freight rate. Source: constructed by the author

Transshipment rates

Transshipment rates for different directions are presented in Figure 8.

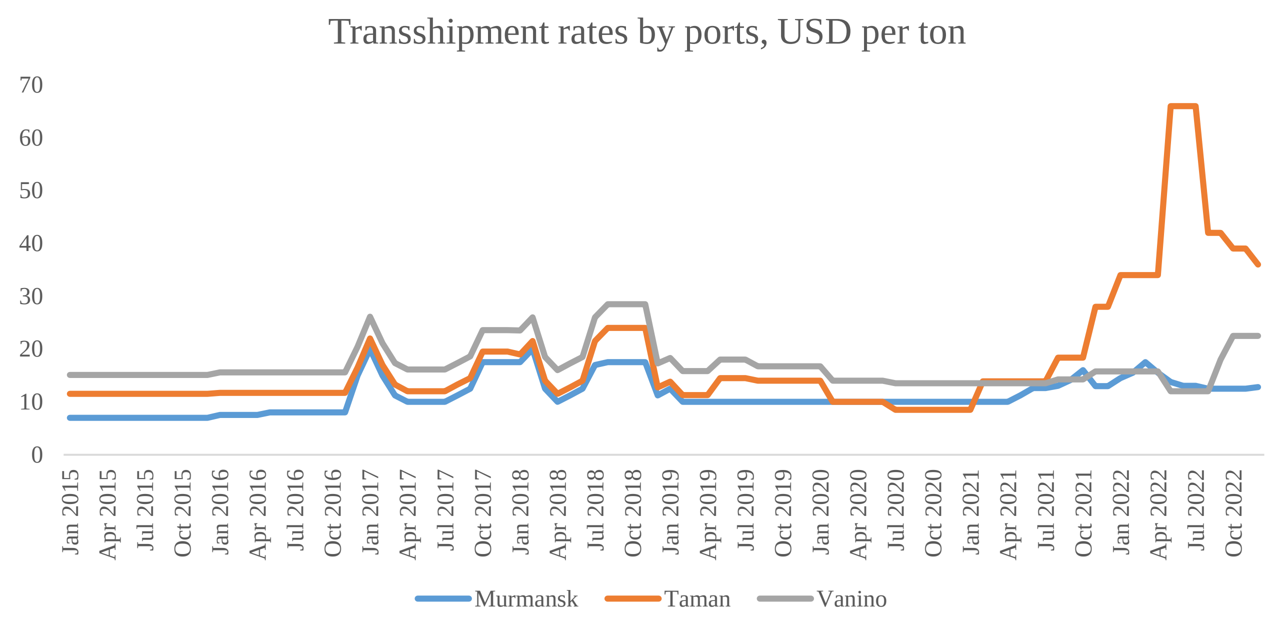

Figure 8. Monthly transshipment rates for coal in ports in 2015-2022. Source: Argus database

Transshipment rates in the period from January 2015 to July 2021 are characterized by relative stability, with small spikes in January 2017, January 2018 and July-October 2018.

At the beginning of 2020, transshipment rates in the southern ports of Russia decreased by $0.75-4 per ton in January compared to mid-2019. According to the Argus agency, this is due to a decrease in coal prices in foreign markets, and for the southern direction it also indicates limited demand for the product in Turkey and southern Europe[46]. The cost of transshipment in most ports of the Far East also decreased compared to 2019 on the back of low global coal prices and increased competitive supply from Australia and Indonesia.

In 2022, due to high demand for coal transshipment in southern ports, its cost reached an “unprecedented level” of more than $60/t[47].

Railway tariffs

From the mining site to the ports, the main mode of transport for coal is rail transport, and the main type of wagons for transporting coal are open wagons (gondola cars). It should be noted that the transportation of coal in containers is now gaining popularity, but the volume of transportation by this type of container is still too small, and the prospects for this direction are still a subject of debate in

[46] https://www.avant-partner.ru/news/12721.html
[47] https://www.vedomosti.ru/business/articles/2022/08/30/938175-pravitelstvo-ischet-puti-eksporta-uglya

professional communities[48]. Thus, in the current study, the assumption is made that coal is transported in gondola cars. Gondola car rental rates are also determined by market demand and supply, as are freight rates and transshipment rates. It should also be noted that the gondola car rental market is formed regardless of the directions of transportation.

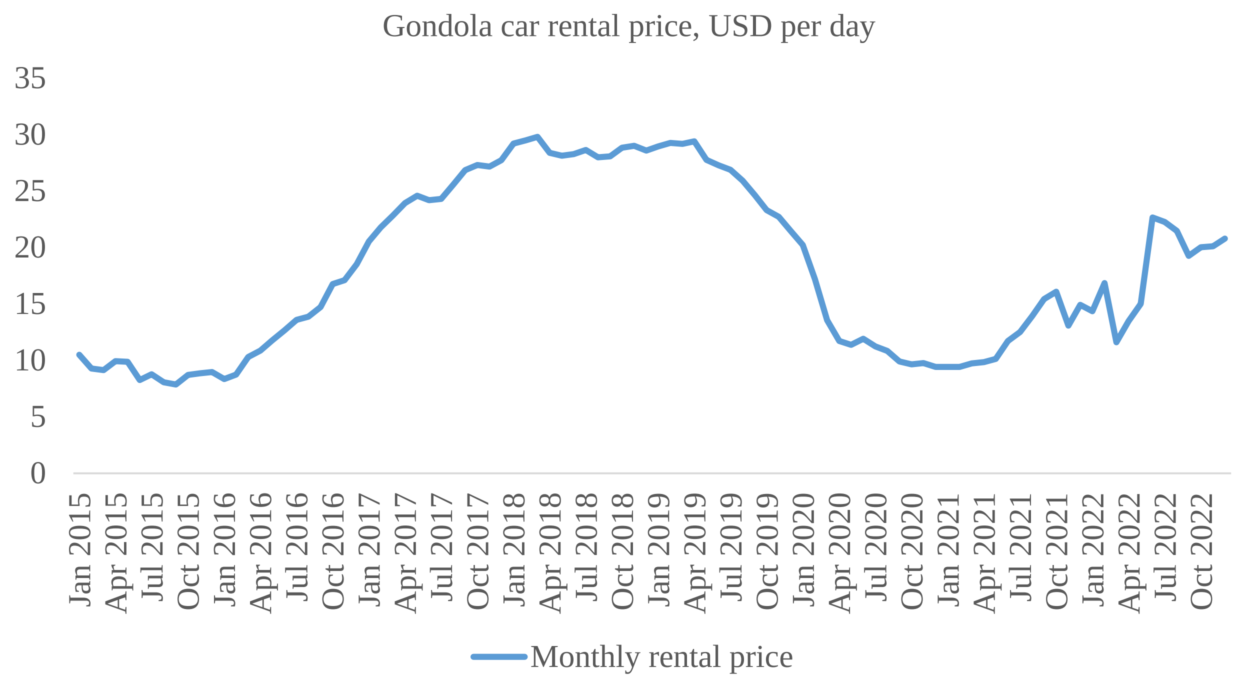

Figure 9. Gondola cars rental price in Russia, USD per day. Source: Pro-Vagon database

From the beginning of the pandemic until the middle of 2021, operators were forced to conduct business at ultra-low rates at the level of the cost of maintaining wagons, and the restoration of rates made it possible to compensate for losses[49].

The main reason for the formation of the current dynamics is a reduction in demand for gondola cars due to a decrease in loading of the largest customers due to logistical restrictions.

Freight days from Vanino port to Chinese port

In order to estimate the volatility in days for sending coal from the port of Vanino to the port of Guangzhou, an unloading from the AXS Dry site was formed for ships with a deadweight of more than 80 thousand tons with dates of departure from the port of Vanino and entry to the port of

[48] https://www.rzd-partner.ru/zhd-transport/comments/perevozka-uglya-i-drugikh-nasypnykh-gruzov-v-konteynerakh-novaya-universalnost-ili-novye-slozhnosti/

[49] https://vgudok.com/lenta/fas-prostavlyaetsya-za-vagony-eksperty-i-antimonopolshchiki-izuchayut-rynok-stavok-arendy-na

Guangzhou. The download does not include data for 2022 because at the time of the download, data for 2022 was not yet available

In total, from 2015 to 2021, 62 vessels passed from the port of Vanino to the port of Guangzhou with a deadweight of more than 80 thousand tons. A full list of ships and arrival dates can be found in Appendix 3.

Distribution density plot of the number of days is shown in Figure 10.

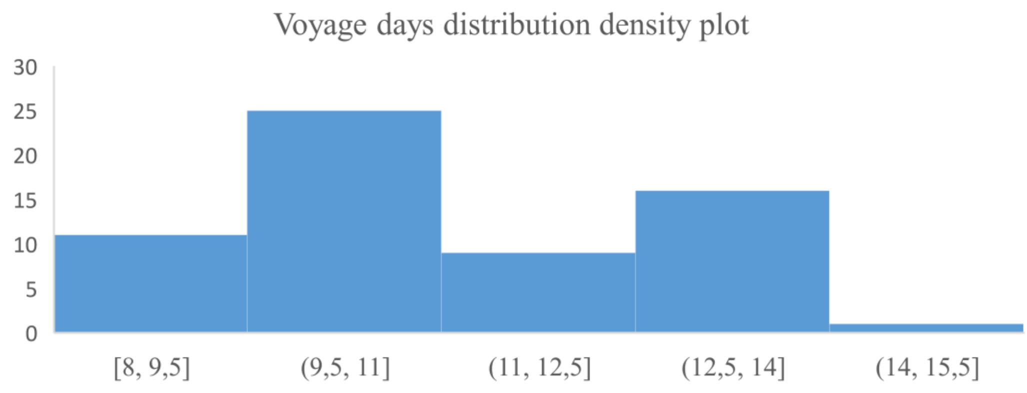

Figure 10. Voyage days distribution histogram of coal bulker ships from Vanino to Guangzhou in 2015-2021. Source: constructed by the author based on AXS Dry database

A triangular distribution is a continuous distribution bounded on both sides. The triangular distribution is often used when information is insufficient or completely absent, and 62 ships over 7 years can be considered a small sample. It rarely can accurately represent a set of values. Despite this, due to its ease of use, it is used as a functional form of representing areas with fuzzy logic. It was proven that the triangular distribution is very useful in various aspects of business problems (Fairchild, Misra and Shi, 2016).

Thus, we will assume that a random variable describing the number of days is distributed according to a triangular distribution law. The triangular distribution parameters are calculated using the following formulas:

$$E[X] = \frac{a + m + b}{3},$$

$$V[X] = \sigma^2 = \frac{a(a - m) + b(b - a) + m(m - b)}{18},$$

Where

a – minimum sample value,

b – maximum sample value,

m – mode of a distribution.

The calculated parameters for this distribution of a random variable are presented in the table

Table 5. Parameter estimation results for voyage days of transportation from Vanino to Guangzhou. Source: constructed by the author

Parameter	Parameter estimation
Minimum (a)	8
Maximum (b)	15
Mode (m)	11
Expected value (E[X])	11.3
Variance (V[X])	2.1
Standard deviation (σ)	1.43

Freight days from Murmansk port to Chinese port via Southern Sea Route

The number of days of departure from Murmansk to the port of Guangzhou was determined in the same way as from the port of Vanino. In total, in 2015-2021, 24 shipments were made by ships with a deadweight of more than 90 thousand tons. Also, for the correctness of data comparison, when unloading this data array, it was indicated that those ship passages that passed through the Suez Canal were unloaded. A sample of data is presented in Appendix 3.

Distribution density plot of the number of days from Murmansk to Guangzhou is shown in Figure 6.

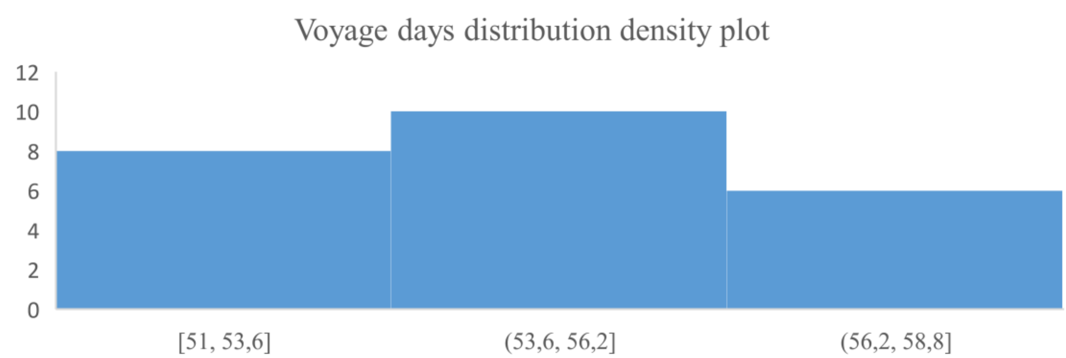

Figure 11. Voyage days distribution histogram of coal bulker ships from Murmansk through Suez Canal to Guangzhou in 2015-2021. Source: constructed by the author based on AXS Dry database

By the principle described in the previous section of this paragraph, it is assumed that a given distribution of a random variable follows a triangular distribution law. The estimated parameters for this random variable are presented in the Table 6

Table 6. Parameter estimation results for voyage days of transportation from Murmansk to Guangzhou. Source: constructed by the author

Parameter	Parameter estimation
Minimum (a)	51
Maximum (b)	58
Mode (m)	52
Expected value (E[X])	53.7
Variance (V[X])	2.4
Standard deviation (σ)	1.55

Freight days from Taman port to Chinese port via Southern Sea Route

For the period 2015-2021 22 vessels with a deadweight of more than 90 thousand tons were sent from Taman to Guangzhou. Data for estimating the number of days to transport coal from Taman to Guangzhou are presented in Appendix 5. The distribution density function for a random variable describing the number of days required for the cargo to reach Guangzhou from Taman is presented in Figure 12.

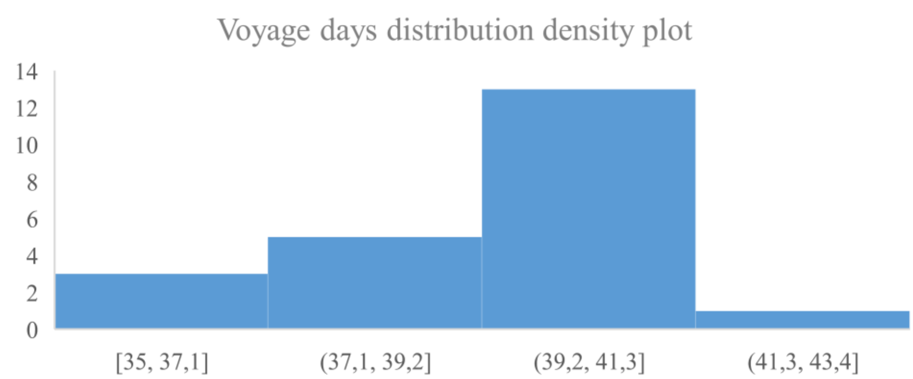

Figure 12. Voyage days distribution histogram of coal bulker ships from Taman to Guangzhou in 2015-2021. Source: constructed by the author based on AXS Dry database

By the principle described in the previous section of this paragraph, it is assumed that a given distribution of a random variable also follows a triangular distribution law. The estimated parameters for this random variable are presented in the Table 7:

Table 7. Parameter estimation results for voyage days of transportation from Taman to Guangzhou. Source: constructed by the author

Parameter	Parameter estimation
Minimum (a)	35
Maximum (b)	42
Mode (m)	40
Expected value (E[X])	39.0
Variance (V[X])	2.2
Standard deviation (σ)	1.47

Freight days via Northern Sea Route

In connection with the assumption that there are differences in the level of uncertainty in the delivery time for the summer period of navigation along the Northern Sea Route and for the winter period of navigation, it is proposed to consider the samples for the Northern Sea Route in summer and winter separately.

Data on days along the Northern Sea Route was downloaded from the site of the Administration of the Northern Sea Route. However, in the data of the Administration of the Northern Sea Route there is no division into bulk, tanker, container and other vessels. Also, there is no separation by deadweight, which is an important criterion for determining the number of days for the current study, since there are differences in the speed of passage of routes by ships of different sizes (and, accordingly, different deadweights).

In order to understand the ship type and ship deadweight (for the sake of comparison), this data was matched with the database of all known ships from the Clarkson company, which has information on the type of ships and its deadweight. Also, the data was connected to another database of the Northern Sea Route Administration to understand the ice class of the vessel. The current study suggests that arctic class vessels of Arc 4 and above are required.

Moreover, in the data of the Administration of the Northern Sea Route there is no data on the end and starting point of the ship's route, but there is data on its movements along the water area of the Northern Sea Route, in particular, its longitude and latitude. These movement data were processed as follows: each point of the vessel's location was compared with the entry of this vessel into one of the 7 areas of the Northern Sea Route (7 areas of the Northern Sea Route are presented in the Rules for the use of the Northern Sea Route, as well as in Figure 8). Further, those ships were selected that for 1 period of time (half a year) were simultaneously in 0 and 1 regions and in 6 and 7 regions of the Northern Sea Route (0 and 1 regions include everything that goes from Murmansk to the Kara Gates and the south part of Kara Sea, in 6 and 7 regions they include including Cape Dezhnev). Then it was manually verified that these vessels had indeed passed all 7 areas of the Northern Sea Route, and a verification was also carried out that these vessels had reached Cape Dezhnev.

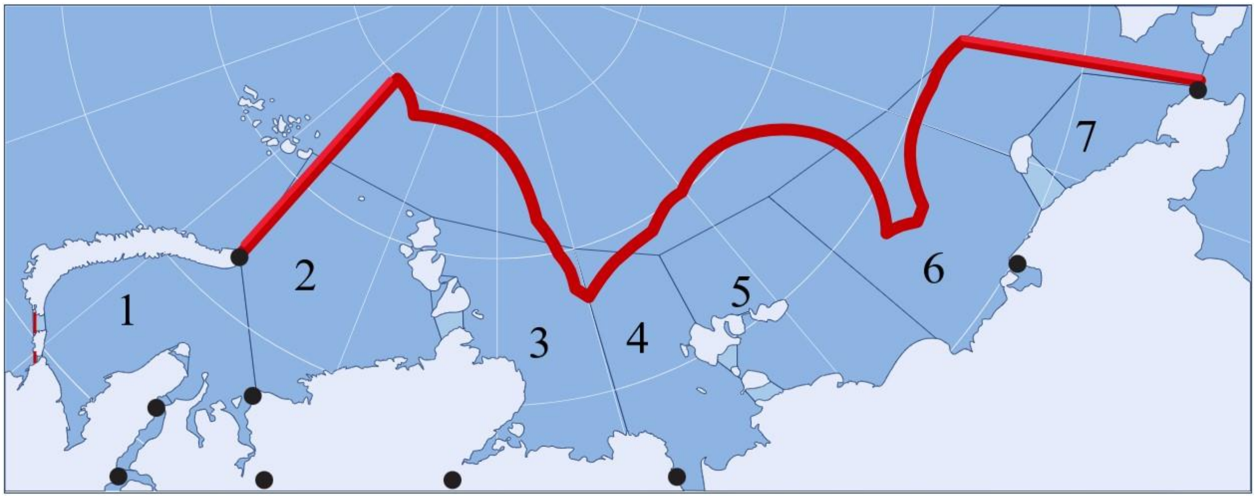

Figure 13. North Sea Route areas. Source: North Sea Route Administration site

However, in order to estimate how many days it would take from Cape Dezhnev (Anadyr port) to the port of Guangzhou, it was assumed that there is no volatility in the remaining segment and that the number of days from Cape Dezhnev to Guangzhou is 8 days[50]. This assumption is one of the limiting factor of this study.

Data on the number of days that ships passed in the summer along the Northern Sea Route are presented in Appendix 4.

The distribution density function for a random variable describing the number of days required for the cargo to reach Guangzhou from Murmansk through the Northern Sea Route is presented in Figure 9.

[50] https://www.searates.com/ru/services/distances-time/

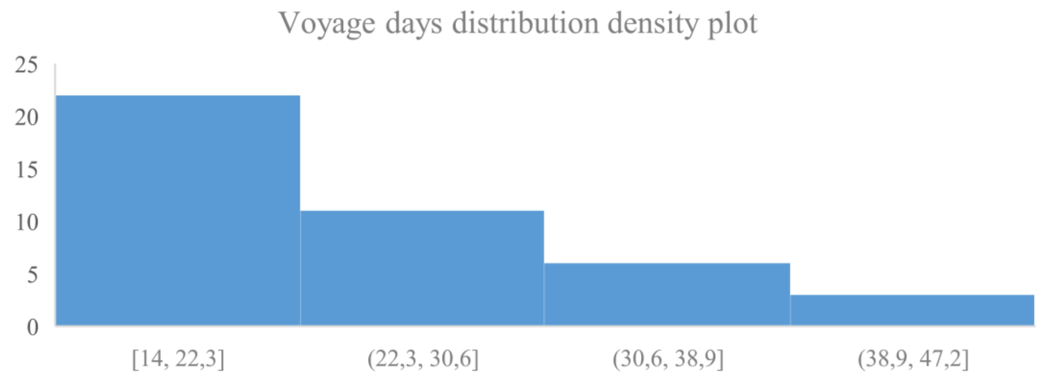

Figure 14. Voyage days distribution histogram of bulker ships from Murmansk to Guangzhou through NSR in 2015-2021. Source: constructed by the author based on Northern Sea Route Administration and Clarksons data

The estimated parameters for this random variable are presented in the Table 8. It is worth noting here that in the estimation of the parameters it is taken into account that the ship will go for another 8 days from Cape Dezhnev to the port of Guangzhou

Table 8. Parameter estimation results for voyage days of transportation from Murmansk to Guangzhou through NSR. Source: constructed by the author

Parameter	Parameter estimation
Minimum (a)	14
Maximum (b)	46
Mode (m)	18
Expected value (E[X])	26.0
Variance (V[X])	50.7
Standard deviation (σ)	7.1

Data on the number of days that ships passed in the winter along the Northern Sea Route are presented in Appendix 6. The distribution density function for a random variable describing the number of days required for the cargo to reach Guangzhou from Murmansk through the Northern Sea Route is presented in Figure 15.

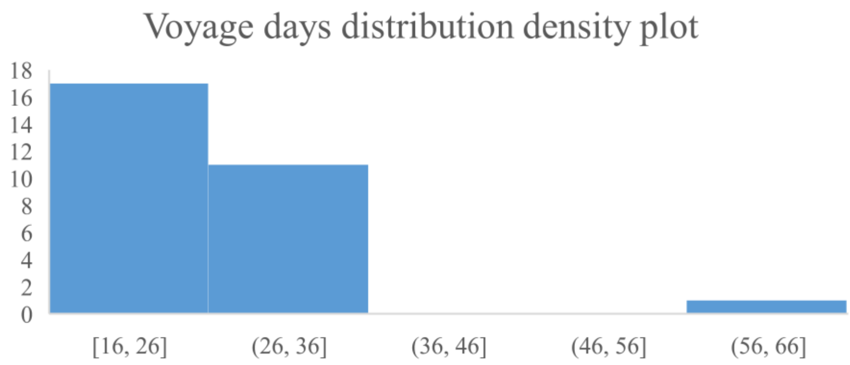

Figure 15. Voyage days distribution histogram of bulker ships from Murmansk to Guangzhou through NSR in winter in 2015-2021. Source: constructed by the author based on Northern Sea Route Administration and Clarksons data

It is also assumed that the random variable is distributed according to a triangular distribution law. The estimated parameters for this random variable are presented in the Table 9:

Table 9. Parameter estimation results for voyage days of transportation from Murmansk to Guangzhou through NSR. Source: constructed by the author

Parameter	Parameter estimation
Minimum (a)	16
Maximum (b)	59
Mode (m)	28
Expected value (E[X])	34.3
Variance (V[X])	82.1
Standard deviation (σ)	9.1

Data forecasting

In order to compile the Markowitz portfolio, it is necessary to predict the values of random variables for 2023. For non-price parameters (in this study, the non-price parameter is the number of days of delivery), the assumption will be made that the parameters of the distribution law, which was found for the period from 2015 to 2021, are preserved.

In this sector, a forecast is presented for the price parameters of the current model: freight rates in different directions, transshipment rates in ports and the rental rate for gondola cars.

In real data, there are often no distinct regular components. Individual observations contain significant error, while you want to not only isolate the regular components, but also make a prediction. The ARIMA methodology developed by Box and Jenkins (1976) allows not only to identify regular components, but also to build a forecast. This method is extremely popular in many applications, and practice has proven its power and flexibility (Hoff, 1983; Pankratz, 1983; Vandaele, 1983). Thus, the current section will show how this model is applicable for various tariff data parameters. ARIMA model for the non-stationary time-series X has the following form:

$$\Delta^d X_i = c + \sum_{i=1}^{p} a_i \Delta^d X_{t-i} + \sum_{j=1}^{q} b_j \varepsilon_{t-j} + \varepsilon_t,$$

Where

ε_t – white noise,

c – constant,

a_i - autoregressive coefficients,

b_j - moving average coefficients.

Δ^d - time series difference operator of order d.

All tariff data forecasting calculations were made using the Stata package.

If there are multiple suitable models with significant parameters and significant models, the Akaike Information Criterion can be used to select the best model. The AIC value is calculated using the following formula:

$$AIC = \frac{-2}{T} \ln(L) + \frac{2}{T} k$$

According to Tsay (2010), the selection process is simple - we need to opt for the model that has the lowest AIC, where AIC is calculated using the maximum-likelihood estimate (L) and the sample size (T).

Freight rates for transportation from Vanino to Guangzhou

To identify stationarity in time series, the analysis will involve examining the plots of series differences and applying a formal method known as the Augmented Dickey-Fuller test. This test is designed to determine the presence of a unit-root in time series, and assesses the extent to which a trend defines a time series. The test is based on the following hypotheses:

- Null hypothesis (H0): A unit root is present, indicating non-stationarity
- Alternative hypothesis (H1): A unit root is not present, indicating stationarity.

By examining the p-value of the test result, we draw conclusions. The decision rules are as follows:

- If the p-value from the test result is greater than 0.05, we do not reject the null hypothesis, indicating that our time-series data is non-stationary and contains a unit root.
- If the resulting p-value from the test is equal to or less than 0.05, we reject the null hypothesis and conclude that our time-series data is stationary.

The results of testing freight rates for stationarity from Vanino are shown in the Table 10. Since p-value is greater than 0.05, we do not reject the null hypothesis and conclude that our data is non-stationary.

Table 10. ADF test for stationarity results for Vanino freight data. Source: calculated by the author

Dickey-Fuller test for unit root				
			N obs:	95
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-1.372	-3.517	-2.894	-2.582

MacKinnon approximate p-value for Z(t) =0.5958

The next step is to check for the presence of a seasonal component in the current data. The result of finding the seasonal component is shown in Figure 17. Also, we will adjust the data for seasonality and check how the graph changes.

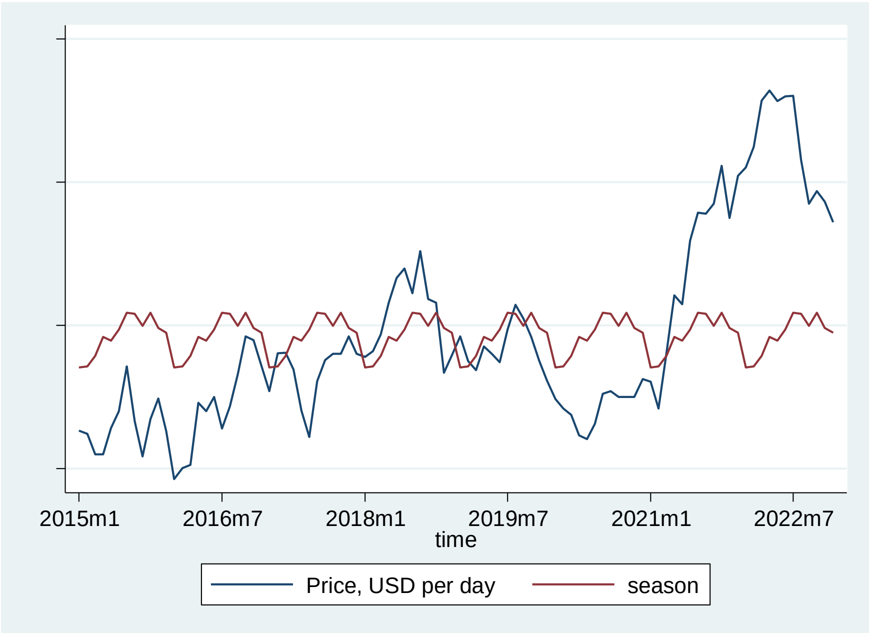

Figure 16. Seasonal component for Vanino freight rates. Source: constructed by the author

As can be seen in Figure 18, despite the presence of a seasonal component, the chart has not changed much. Therefore, for further analysis, we will assume that seasonality is weakly expressed in the current data and we do not take it into account. The code in the Stata program for detecting the seasonal component is given in Appendix 6.

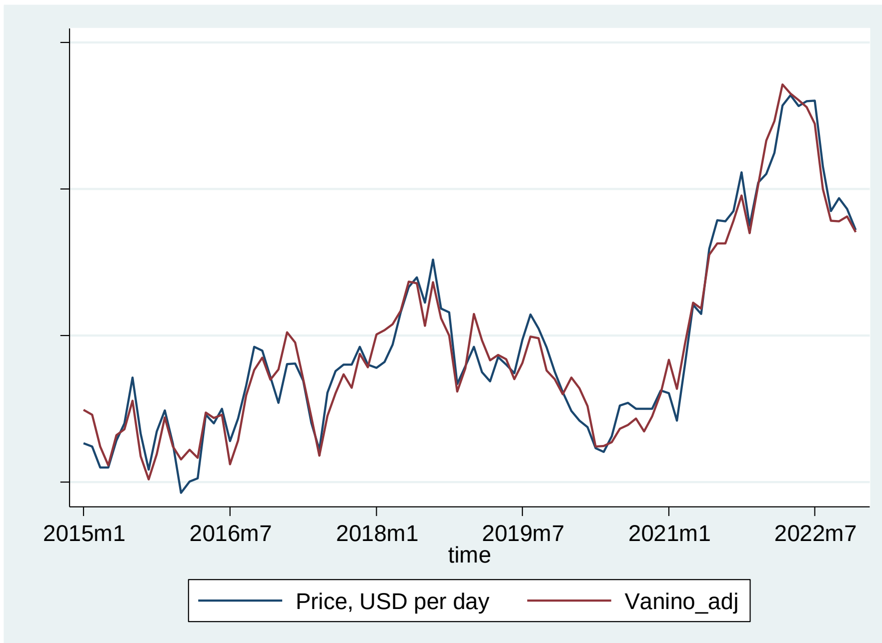

Figure 17. Freight rate from Vanino with adjustments for seasonal component. Source: constructed by the author

Next, we find the first difference and check it for stationarity using the Dickey-Fuller test. This series is already stationary (the null hypothesis that the series is non-stationary is rejected) and we can continue to work with it.

Table 11. ADF test for stationarity results for Vanino freight data first difference. Source: calculated by the author

Dickey-Fuller test for unit root				
			N obs:	94
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-9.073	-3.518	-2.895	-2.582

MacKinnon approximate p-value for Z(t) =0.0000

Next, a selection of various variants of model configurations was made. The only significant model with significant parameters with the least number of parameters of the ARIMA model turned out to be the ARIMA model (2,2,0). The simulation results are presented in the Table 12. As can be seen in the figure, the p-value for the model and for the parameters (excluding the constant) is less than 0.05, which means that we will reject the null hypothesis about the insignificance of the parameters and the model. Thus, both the parameters and the model are significant and can be used to predict the data.

Table 12. ARIMA model construction results. Source: constructed by the author

ARIMA regression model results						
:		N obs:	94			
		Wald chi2(2)	31.89			
		Prob>chi2 (p-value)	0.00			
		Log likelihood	-1014.12			
Coefficient	Estimate	Std. Error	z	p-value	95% Conf. Interval	
Vanino						
Intercept	-14.45	647.08	-0.02	0.98	-1282.97	1253.79
ARMA						
L1	-0.57	0.10	-5.46	0.00	-0.77	-0.36
L2	-0.33	0.09	-3.63	0.00	-0.51	-0.15

The data is forecasted for the next 12 months of 2023. A graph showing the forecast model and actual data is shown in Figure 18. The graph shows that the predictive model is very close to the actual data, which indicates that its construction is satisfactory.

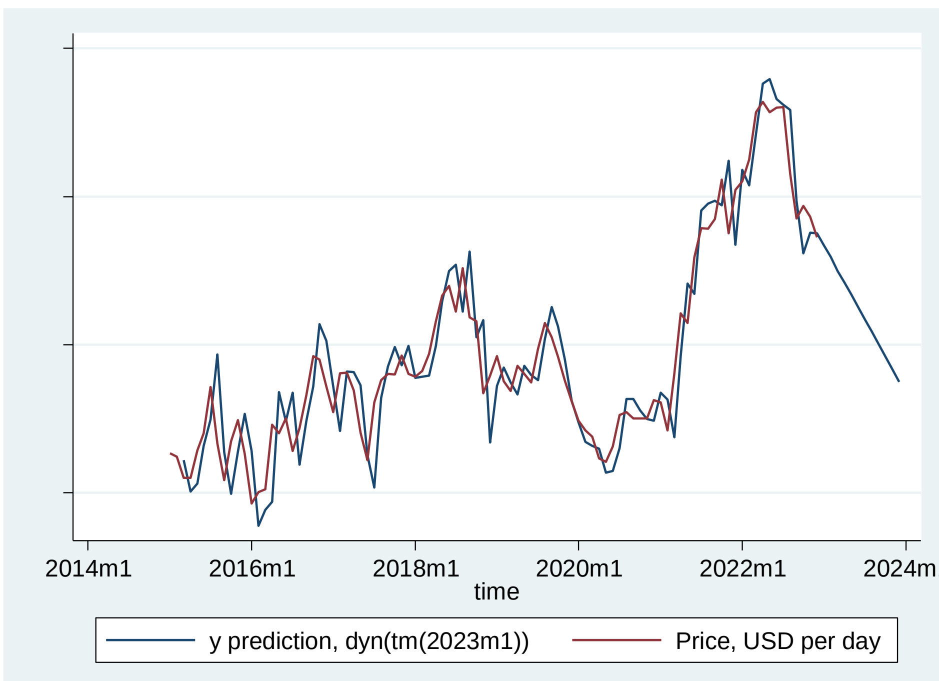

Figure 18. Forecast for 12 months of freight rates from Vanino to Guangzhou. Source: constructed by the author.

Freight rates for transportation from Murmansk to Guangzhou through the Suez Canal

Forecasting data for transportation by sea from Murmansk is carried out according to the same scheme as for Vanino. First, we test the data for stationarity. According to the result of the Dickey-Fuller test, the data is non-stationary.

Table 13. ADF test for stationarity results for Murmansk freight data. Source: calculated by the author

Dickey-Fuller test for unit root				
			N obs:	95
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-0.992	-3.517	-2.894	-2.582

MacKinnon approximate p-value for Z(t) =0.7563

Thus, we test the data for stationarity of the first differential.

Table 14. ADF test for stationarity results for Murmansk first difference freight data. Source: calculated by the author

Dickey-Fuller test for unit root				
			N obs:	94
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-6.987	-3.518	-2.895	-2.582

MacKinnon approximate p-value for Z(t) =0.0000

The first difference data is stationary; it is possible to continue to work with it.

The next step was to check for seasonality. As in the previous case, although there is seasonality, it is not very significant, so we will neglect it in order to predict the data. The values of the seasonal component and the corrected graph without seasonality are shown in Figures 19 and 20, respectively.

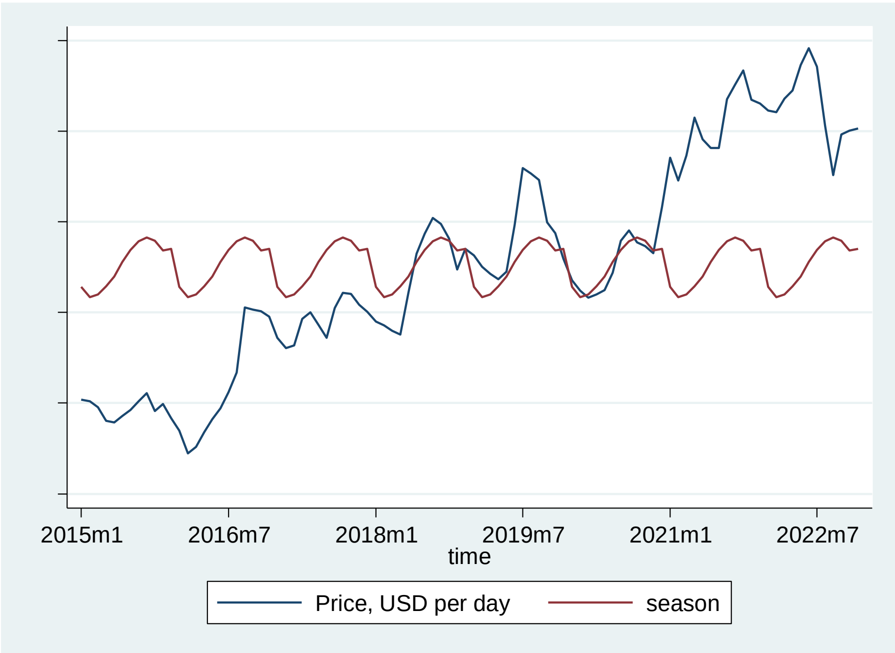

Figure 19. Seasonal component for Murmansk freight rates. Source: constructed by the author

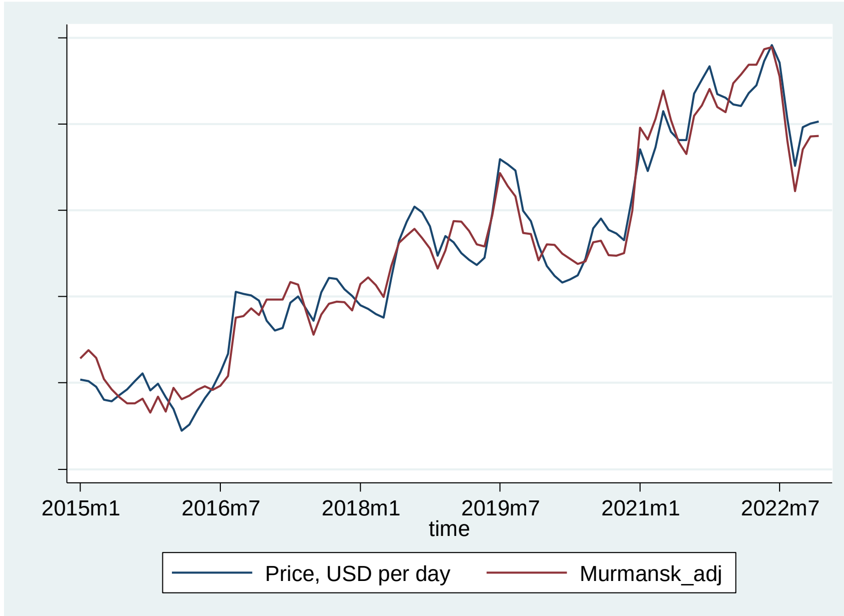

Figure 20. Freight rate from Murmansk with adjustments for seasonal component. Source: constructed by the author

The next step was to build the ARIMA model. The only significant model with significant parameters was the ARIMA model (0,1,1). The results of building the model are shown in Table 15.

Table 15. ARIMA model construction results for Murmansk freight rate. Source: constructed by the author

ARIMA regression model results						
		N obs:		95		
		Wald chi2(2)		12.85		
		Prob>chi2 (p-value)		0.00		
		Log likelihood		-935.79		
Coefficient	Estimate	Std. Error	z	p-value	95% Conf. Interval	
Murmansk						
Intercept	631.50	652.37	0.97	0.33	-647.13	1910.12
ARMA						
L1	0.34	0.95	3.58	0.00	0.15	0.53

The data is forecasted for the next 12 months of 2023. A graph showing the forecast model and actual data is shown in Figure 26. The graph shows that the predictive model is very close to the actual data, which indicates that its construction is satisfactory.

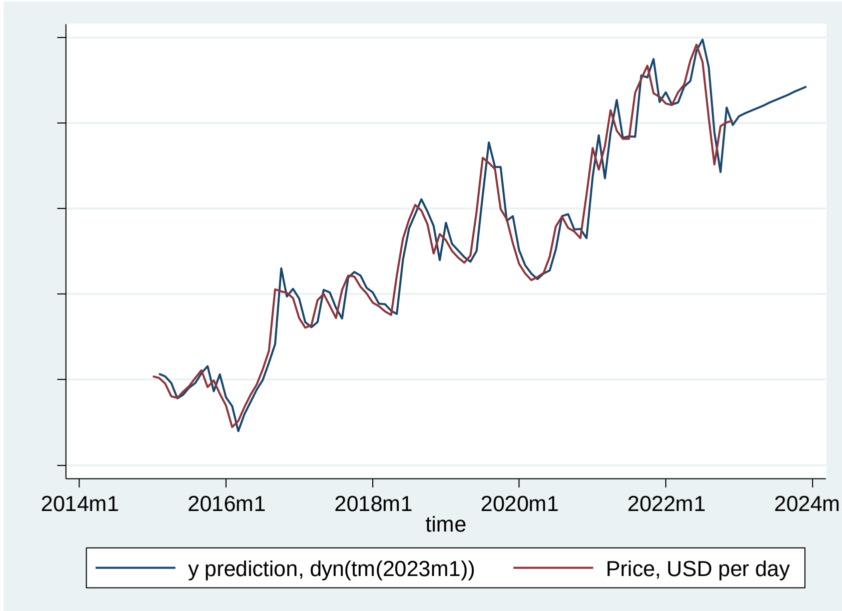

Figure 26. Forecast for 12 months of freight rates from Murmansk to Guangzhou. Source: constructed by the author.

Freight rates for transportation from Taman to Guangzhou

The results of the stationarity test are shown in the Table 16.

Table 16. ADF test for stationarity results for Taman freight data. Source: calculated by the author

Dickey-Fuller test for unit root				
			N obs:	95
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-1.109	-3.517	-2.894	-2.582

MacKinnon approximate p-value for Z(t) =0.7115

Since the data is non-stationary, it is necessary to take the first differential and test for stationarity.

The test results are shown in the Table 17.

Table 17. ADF test for stationarity results for Taman first difference freight data. Source: calculated by the author

Dickey-Fuller test for unit root				
			N obs:	94
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-7.655	-3.518	-2.895	-2.582

MacKinnon approximate p-value for Z(t) =0.0000

The first difference data is stationary, we continue to work with it.

The next step was to check for seasonality. As in previous cases, although there is seasonality, it is not very significant, so we will neglect it in order to predict the data. The values of the seasonal component and the corrected graph without seasonality are shown in Figures 27 and 28, respectively.

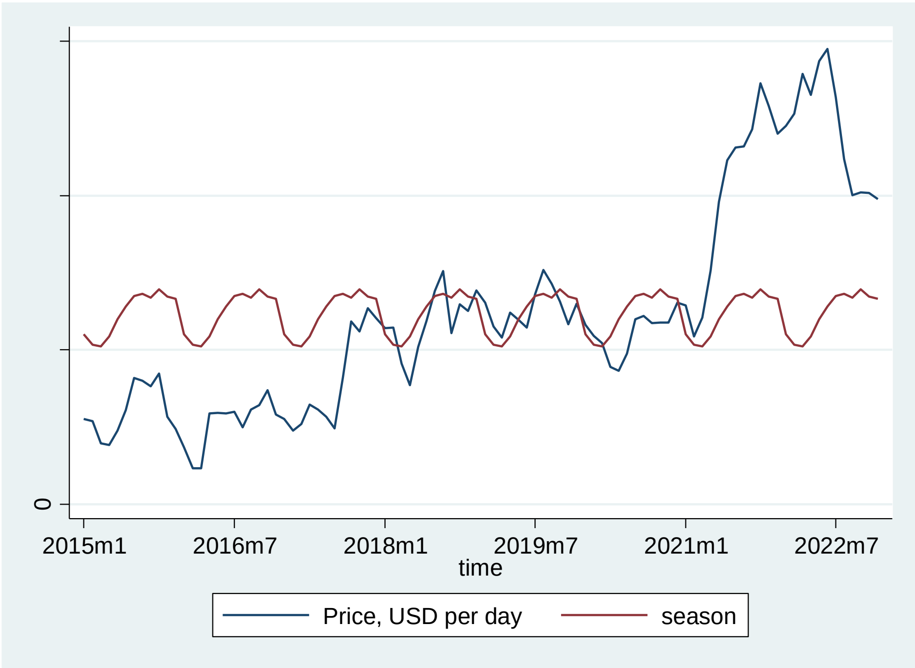

Figure 27. Seasonal component for Taman freight rates. Source: constructed by the author

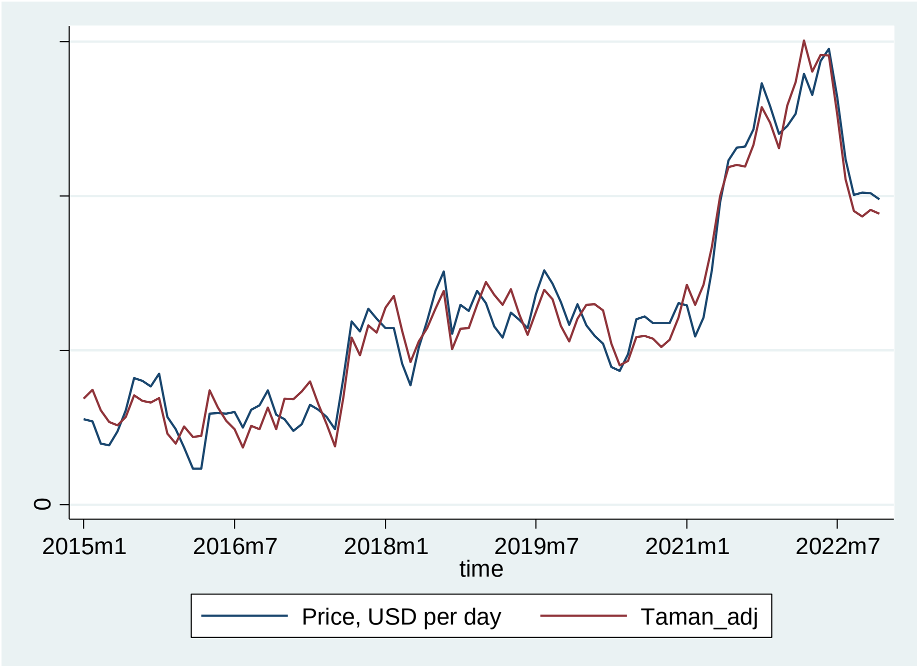

Figure 28. Freight rate from Taman with adjustments for seasonal component. Source: constructed by the author

The next step was to build the ARIMA model. The only significant model with significant parameters was the ARIMA model (0,1,1). The results of building the model are shown in the Table 18:

Table 18. ARIMA model construction results for Taman freight rate. Source: constructed by the author

ARIMA regression model results						
		N obs:		95		
		Wald chi2(2)		7.50		
		Prob>chi2 (p-value)		0.0062		
		Log likelihood		-987.21		
Coefficient	Estimate	Std. Error	z	p-value	95% Conf. Interval	
Taman						
Intercept	745.61	1009.21	0.74	0.46	-1232.40	2723.62
ARMA						
L1	0.25	0.09	2.74	0.01	0.07	0.42

The data is forecasted for the next 12 months of 2023. A graph showing the forecast model and actual data is shown in Figure 29. The graph shows that the predictive model is very close to the actual data, which indicates that its construction is satisfactory.

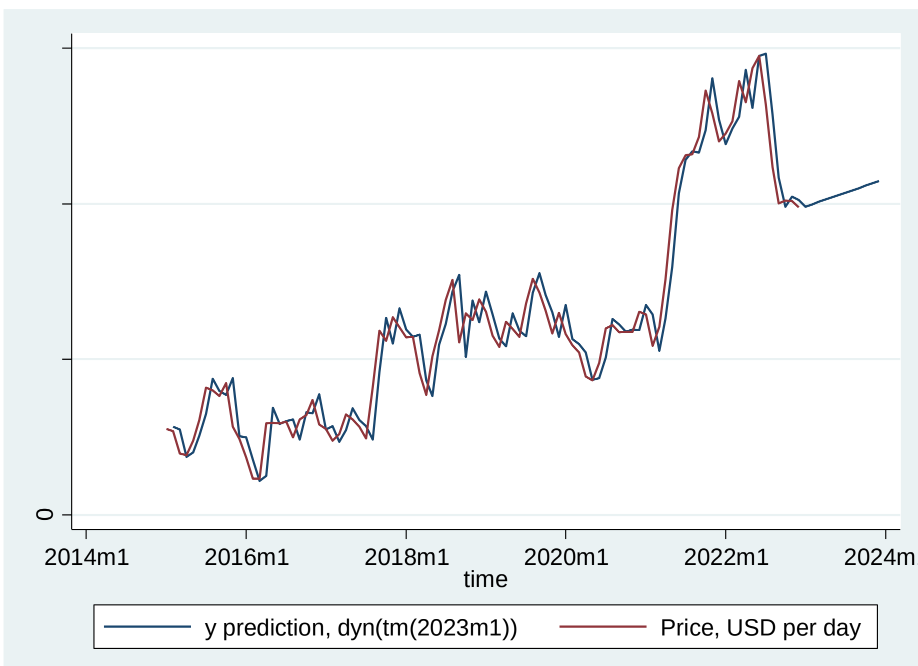

Figure 29. Forecast for 12 months of freight rates from Taman to Guangzhou. Source: constructed by the author

Freight rates for transportation along Northern Sea Route

For the data forecast for the Northern Sea Route, the time data forecast model was needed only for fuel price forecasting. To predict the rest of the parameters, it was assumed that their value would grow with the projected growth rate of US dollar inflation. The predicted inflation rate was taken from the IHS website.

To predict fuel prices, the appropriate procedures are carried out. By the Dickey-Fuller criterion, the series is non-stationary (Table 19), so we will use the stationary first differential (which is stationary by the Dickey-Fuller criterion, as shown in the Table 20)

Table 19. ADF test for stationarity results for VLSFO. Source: calculated by the author

Dickey-Fuller test for unit root				
			N obs:	41
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-1.008	-3.641	-2.955	-2.611
MacKinnon approximate p-value for Z(t) =0.7504				

Table 20. ADF test for stationarity results for VLSFO 1-st difference. Source: calculated by the author

Dickey-Fuller test for unit root				
			N obs:	40
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-4.046	-3.648	-2.958	-2.612
MacKinnon approximate p-value for Z(t) =0.0012				

The presence of a seasonal component was checked. Figure 30 shows that although it exists, it is very weak, which also confirms the similarity of the graphs for the original data and for the data with the removed seasonal component. Therefore, we continue to work with the original data, making the assumption that there is no seasonality in the current data.

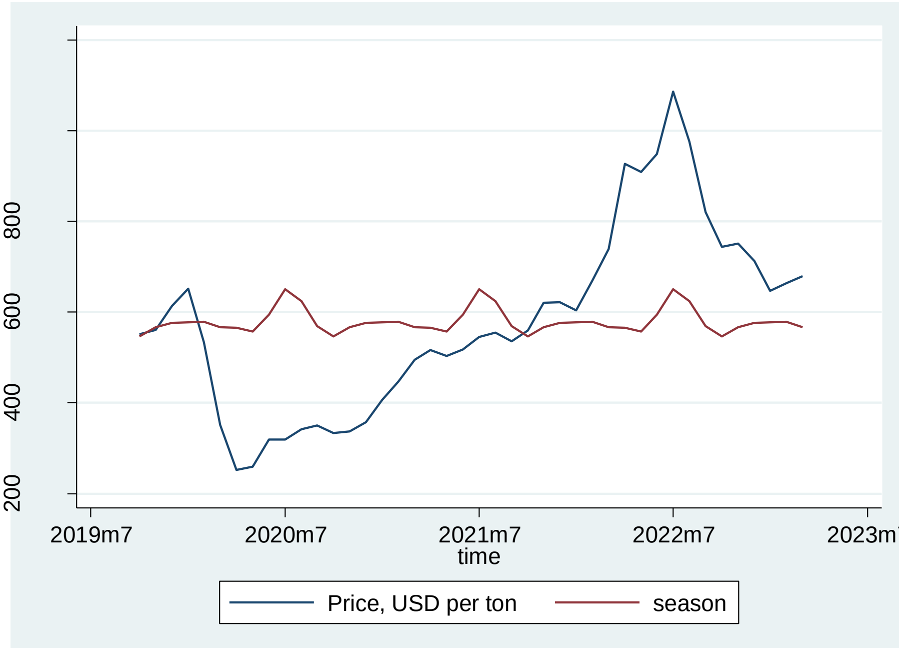

Figure 30. Seasonal component for VLSFO. Source: constructed by the author

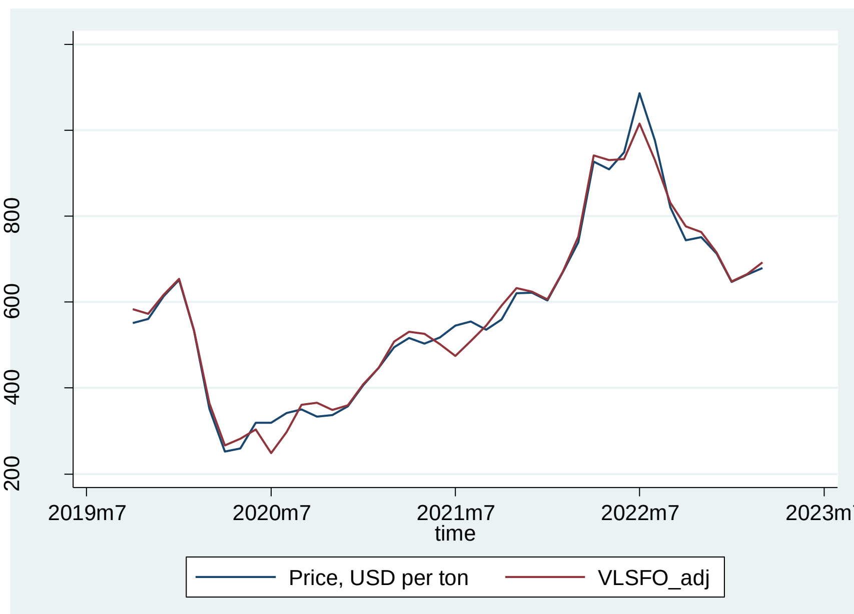

Figure 31. VLSFO with adjustments for seasonal component. Source: constructed by the author

The ARIMA model has been built. The only significant specification of the model along with significant parameters (except for the constant) is the specification of the ARIMA model (0,1,1), the calculation results of which are shown in the Table 21.

Table 21. ARIMA model

ARIMA regression model results						
		N obs:		41		
		Wald chi2(2)		64.75		
		Prob>chi2 (p-value)		0.0000		
		Log likelihood		-226.00		
Coefficient	Estimate	Std. Error	z	p-value	95% Conf. Interval	
VLSFO						
Intercept	2.97	15.98	0.19	0.85	-28.34	34.28
ARMA						
L1	0.64	0.08	8.05	0.00	0.49	0.80

This model specification is used to predict monthly data for 2023, the result of which is shown in Figure 32.

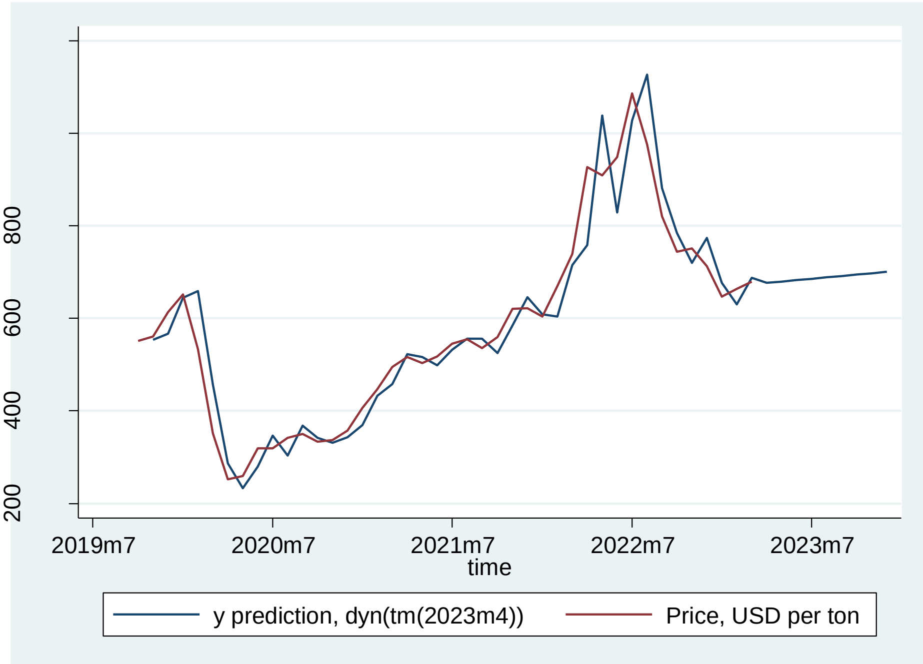

Figure 32. VLSFO prediction

Transshipment rates for Vanino

Testing for stationarity of the time series for transshipment in Vanino was carried out. The P-value is 0.07, which is a fairly low value, but still, at a 95% confidence interval, the null Proposition that the data is non-stationary is accepted, the results are shown in the Table 22.

The first differential of this time series, according to the Dickey-Fuller criterion, is stationary (Table 23).

Table 22. ADF for initial data

Dickey-Fuller test for unit root				
			N obs:	95
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-2.703	-3.517	-2.894	-2.582

MacKinnon approximate p-value for Z(t) =0.0735

Table 23. ADF for first difference

Dickey-Fuller test for unit root				
			N obs:	94
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-8.309	-3.518	-2.895	-2.582

MacKinnon approximate p-value for Z(t) =0.0000

In this case, it can be seen that the data have a high degree of seasonality: the model without the seasonal component differs significantly from the original data (Fig. 33 and 34).

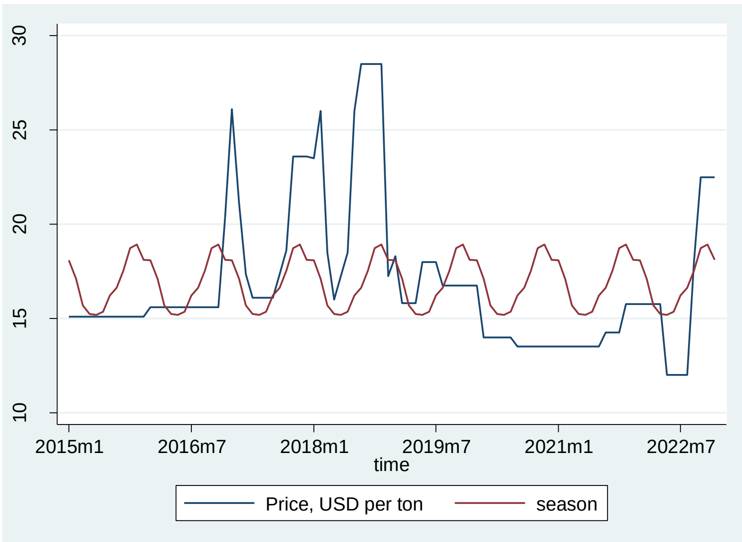

Figure 33. Seasonal component

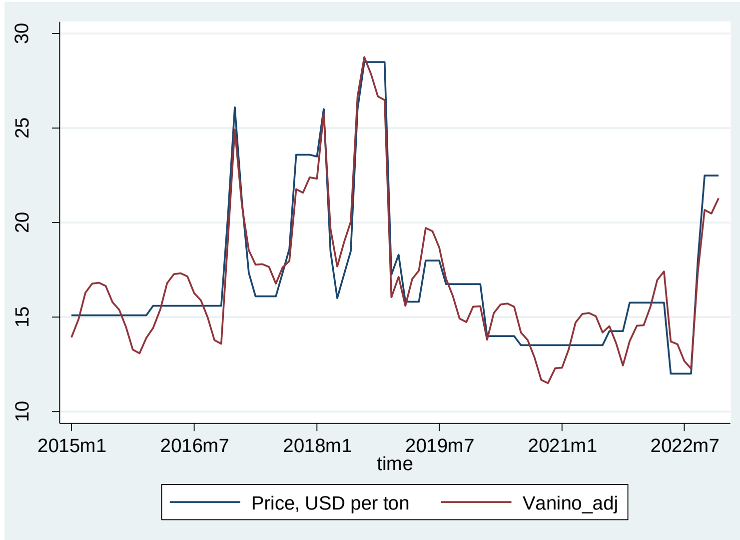

Figure 34. Initial data and adjusted data

Thus, ARIMA models with a seasonal component were tested. The only significant model with a seasonal component was the ARIMA (0,1,0) model with a value of 1 MA in lag number 5 (Fig. 30).

Table 24. ARIMA model

ARIMA regression model results						
		N obs:		95		
		Wald chi2(2)		44.35		
		Prob>chi2 (p-value)		0.0000		
		Log likelihood		-204.92		
Coefficient	Estimate	Std. Error	z	p-value	95% Conf. Interval	
Vanino						
Intercept	0.04	0.17	0.23	0.82	-0.30	0.37
ARMA						
L1	-0.42	0.06	-6.66	0.00	-0.54	-0.30

Table 25. Criteria to choose

Akaike's information criterion and Bayesian information criterion				
			N obs:	95
ll (null)	Ll (model)	df	AIC	BIC
0	-204.92	3	415.84	423.50

Figure 21. Criteria to choose

Also, models without seasonality were considered, but according to the Akaike criteria and the Bayesian information criterion, the seasonally adjusted model better predicts the behavior of this random variable (Tables 24 and 25). Alternative models are presented in Appendices 8-10.

The prediction for the accepted model is shown in Figure 35.

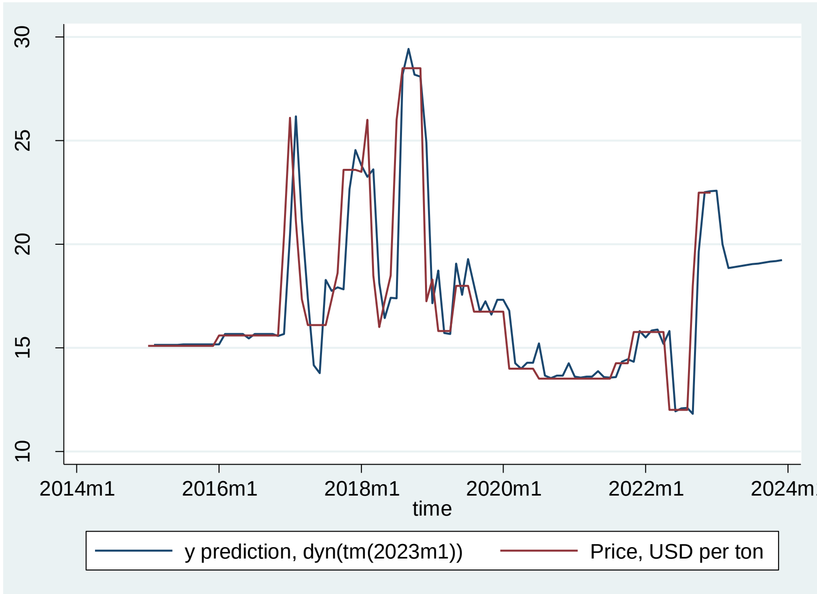

Figure 35. Prediction

Transshipment rates for Murmansk

Testing for stationarity of the time series for transshipment in Vanino was carried out. The P-value is 0.0508, which is pretty close to 0.05, but still, at a 95% confidence interval, the null Proposition that the data is non-stationary is accepted, the results are shown in the Table 26.

The first differential of this time series, according to the Dickey-Fuller criterion, is stationary (Table 27).

Table 26. ADF for initial data

Dickey-Fuller test for unit root				
			N obs:	95
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-2.855	-3.517	-2.894	-2.582
MacKinnon approximate p-value for Z(t) =0.0508				

Table 27. ADF for first difference

Dickey-Fuller test for unit root				
			N obs:	94
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-8.462	-3.518	-2.895	-2.582
MacKinnon approximate p-value for Z(t) =0.0000				

In this case, seasonality also takes place (Fig. 36 and 37): however, we can observe that it is less pronounced than in the port of Vanino. This behavior of the variable can be explained by the fact that Vanino is a much more developed market in coal transshipment due to its proximity to China and seasonality can be traced more on it.

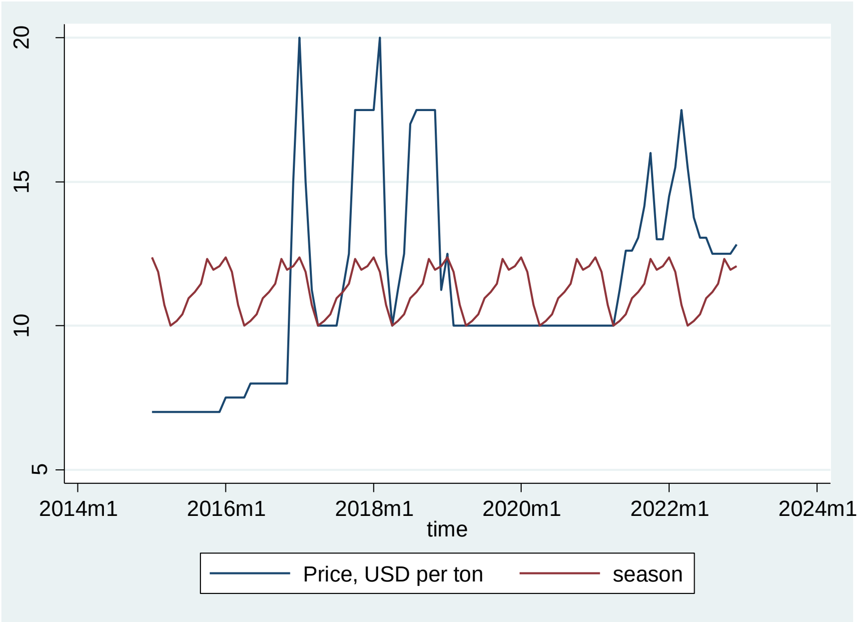

Figure 36. Seasonal component

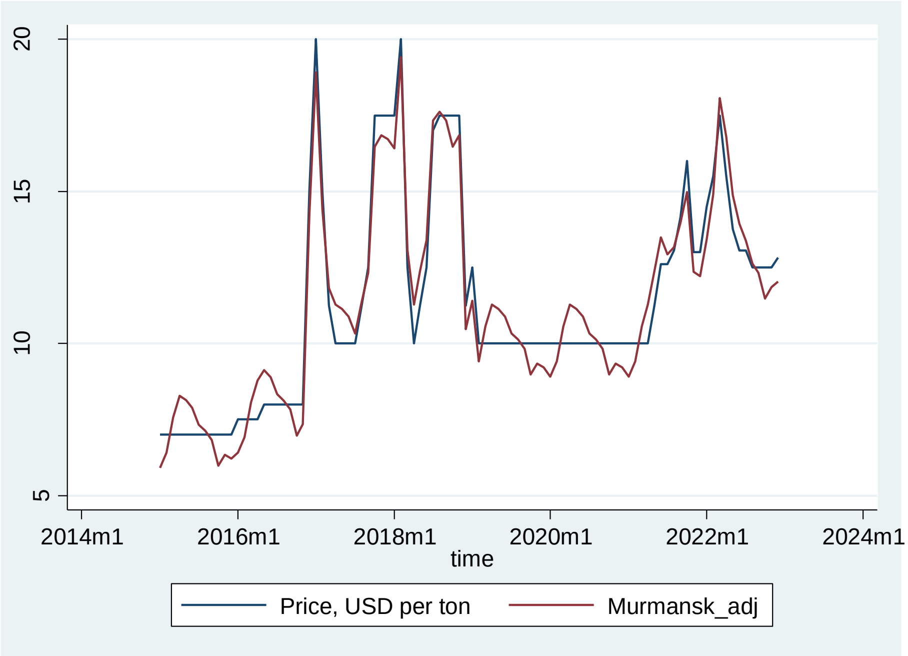

Figure 37. Initial data and adjusted for seasonal component

To select the model configuration, both seasonal and classical ARIMA models were built. The only specification with a meaningful model and parameters (other than a constant) was the ARIMA model (0,1,1). Also, when building seasonal models, ARIMA (0,1,1) with a first-order MA component and a lag of 5 in the seasonal part turned out to be the only significant one. At the same time, it should be noted that the components of the seasonal model are significant only at the 90% confidence interval.

To select the appropriate model specification, the Akaike information criteria and the Bayesian criterion were calculated. According to the Akaike information criterion, both models are equivalent, however, according to the Bayesian criterion, the model without the seasonal component predicts the behavior of the random variable better. The results of the calculation of the alternative model (with a seasonal component) are presented in Appendix 11.

Table 28. ARIMA model results

ARIMA regression model results						
		N obs:		95		
		Wald chi2(2)		4.21		
		Prob>chi2 (p-value)		0.0402		
		Log likelihood		-190.68		
Coefficient	Estimate	Std. Error	z	p-value	95% Conf. Interval	
Murmansk						
Intercept	0.06	0.24	0.26	0.80	-0.40	0.53
ARMA						
L1	0.16	0.08	2.05	0.04	1.68	1.92

Table 29. Information criteria results

Akaike's information criterion and Bayesian information criterion				
			N obs:	95
ll (null)	Ll (model)	df	AIC	BIC
0	-190.68	3	387.37	395.03

Thus, the ARIMA (0,1,1) model without the seasonal component was used for the forecast.

The forecast is shown in Figure 38. Also, the result of the forecast for the model with a seasonal component is presented in Appendix 13. It is noteworthy that the forecast with a seasonal component is very close to the forecast without a seasonal component.

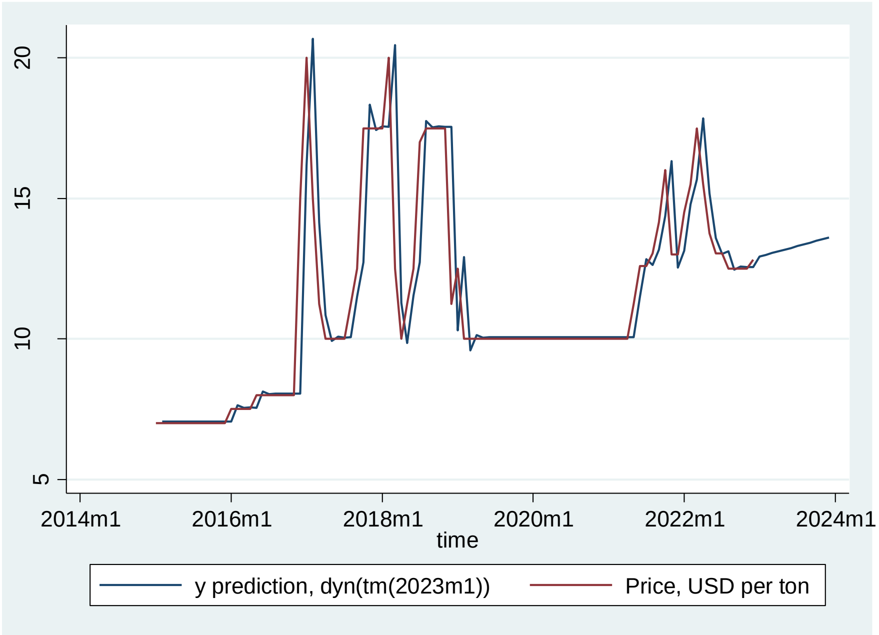

Figure 38. Forecasted variable

Transshipment rates for Taman

To predict transshipment rates, the appropriate procedures are carried out. By the Dickey-Fuller criterion, the series is non-stationary (Table 30), so we will use the stationary first differential (which is stationary by the Dickey-Fuller criterion, as shown in the Table 31)

Table 30. ADF test for initial data

Dickey-Fuller test for unit root				
			N obs:	95
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-1.751	-3.517	-2.894	-2.582
MacKinnon approximate p-value for Z(t) =0.4051				

Table 31. ADF test for first difference

Dickey-Fuller test for unit root				
			N obs:	94
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-9.422	-3.518	-2.895	-2.582
MacKinnon approximate p-value for Z(t) =0.0000				

The seasonal component is highlighted. It can be noted that in these time series the seasonal component is not very significant, so further analysis will be carried out with the assumption that there is no seasonality in this case.

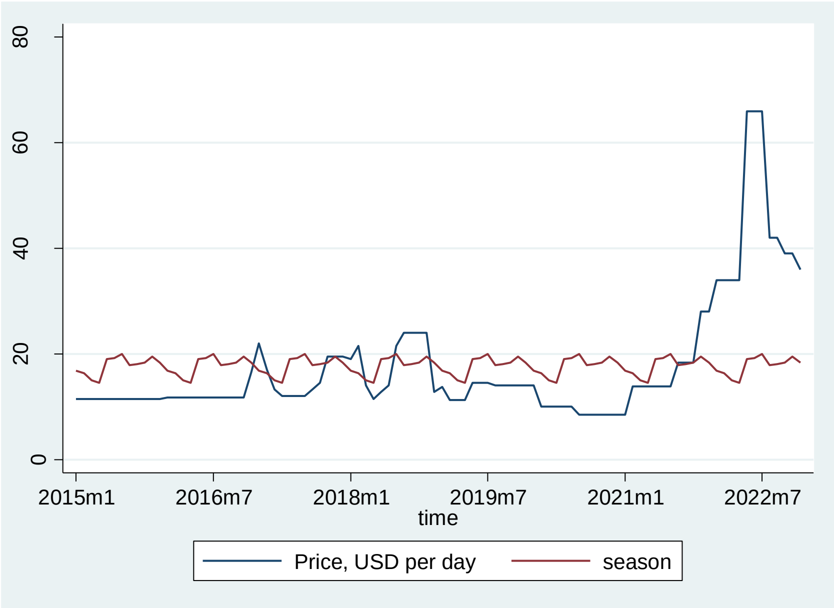

Figure 39. Seasonal component

Figures 39 and 40 show the seasonal component separately and the graph comparing the original data with the graph without the seasonal component, respectively. It can be noted that these graphs are very close to each other.

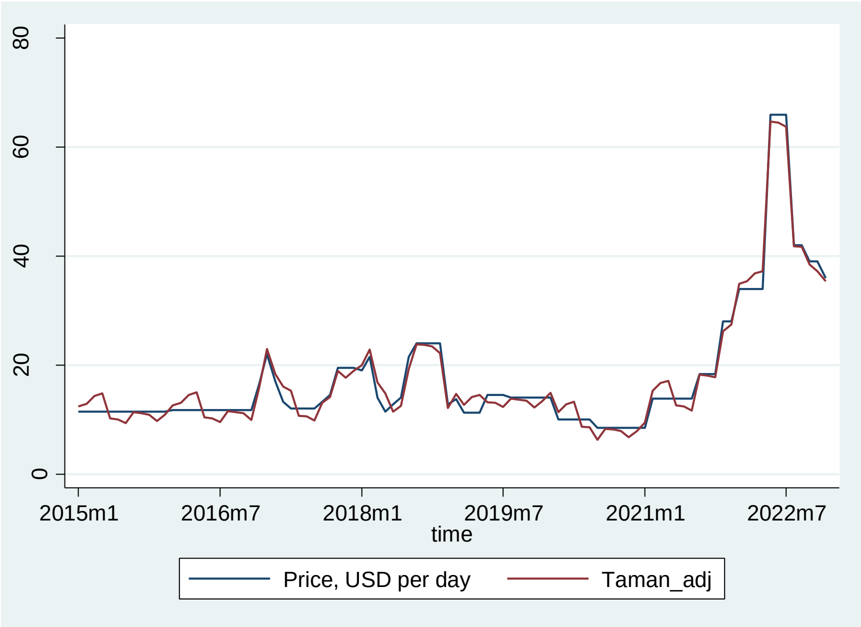

Figure 40. Initial data and adjusted for seasonal component

In this case, the only significant specification of the model with significant variables was the specification of ARIMA (1,1,1). The calculation result is shown in the Table 32.

Table 32. ARIMA model results

ARIMA regression model results						
		N obs:		95		
		Wald chi2(2)		347.13		
		Prob>chi2 (p-value)		0.0000		
		Log likelihood		-282.46		
Coefficient	Estimate	Std. Error	z	p-value	95% Conf. Interval	
Taman						
Intercept	0.24	0.21	1.13	0.26	-0.18	0.66
ARMA						
(AR) L1	0.90	0.05	10.10	0.00	0.80	0.99
(MA) L1	-1	0.06	-15.59	0.00	-1.13	-0.87

The forecast according to the ARIMA model (1,1,1) for the transshipment rate in Taman is shown in Figure 41.

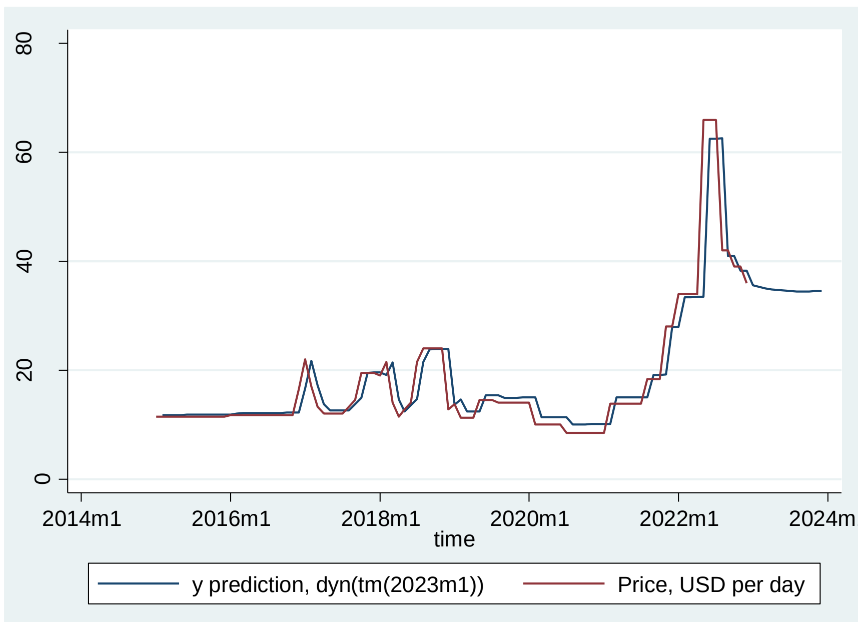

Figure 41. Data forecast

Railway tariffs

According to the Dickey-Fuller criterion, the time series is non-stationary (Table 33), while its first differential is stationary (Table 34)

Table 33. ADF test for initial data

Dickey-Fuller test for unit root				
			N obs:	95
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value

Z(t)	-1.174	-3.517	-2.894	-2.582

MacKinnon approximate p-value for Z(t) =0.6846

Table 34. ADF test for first difference

Dickey-Fuller test for unit root				
			N obs:	94
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-7.814	-3.518	-2.895	-2.582

MacKinnon approximate p-value for Z(t) =0.0000

Analysis of the seasonal component showed that the seasonality of this time series is weakly expressed. (Fig. 42 and 43) Thus, we will carry out further analysis, taking into account the assumption that there is no seasonality in these time series.

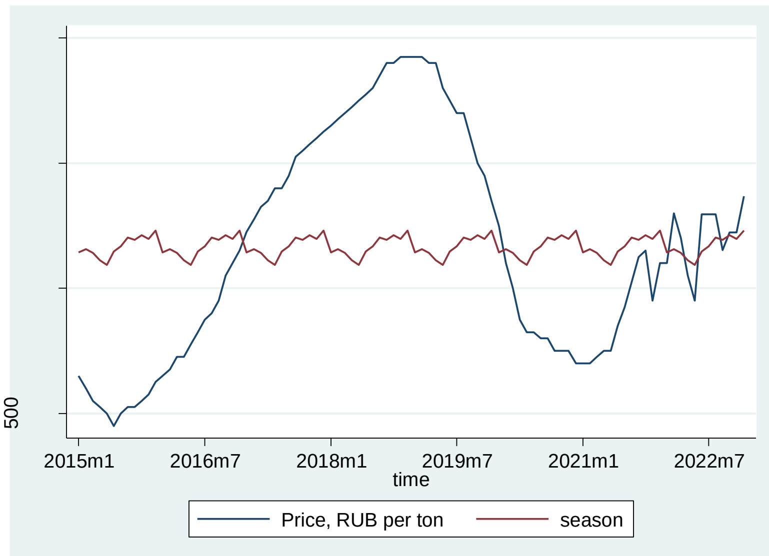

Figure 42. Seasonal component

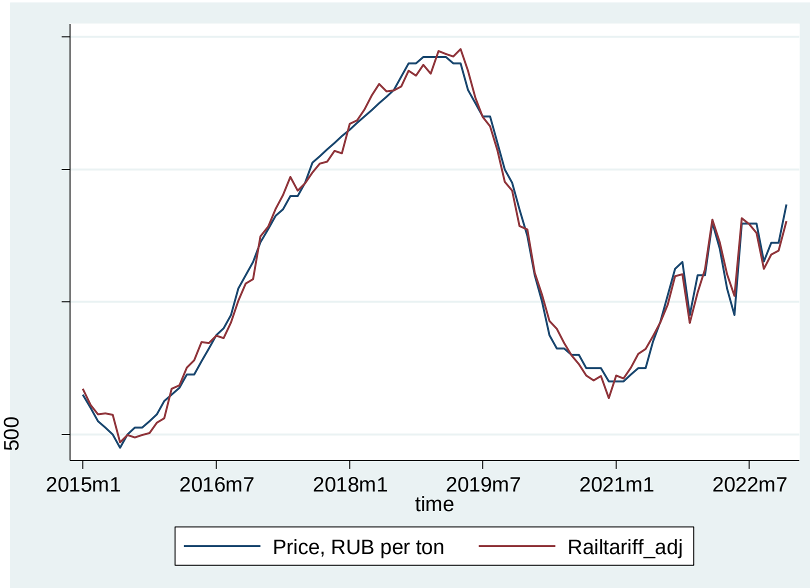

Figure 43. Adjusted data

The only significant model with significant variables was the ARIMA model in the ARIMA specification (1,1,1). The monthly data forecast for 2023 is shown in Figure 44.

Table 35. ARIMA model results

ARIMA regression model results						
		N obs:		95		
		Wald chi2(2)		69.28		
		Prob>chi2 (p-value)		0.0000		
		Log likelihood		-540.10		
Coefficient	Estimate	Std. Error	z	p-value	95% Conf. Interval	
Railtariff						
Intercept	7.70	20.08	0.38	0.70	-31.66	47.06
ARMA						
(AR) L1	0.91	0.14	6.63	0.00	0.64	1.18
(MA) L1	-0.78	0.19	-4.19	0.00	-1.14	-0.41

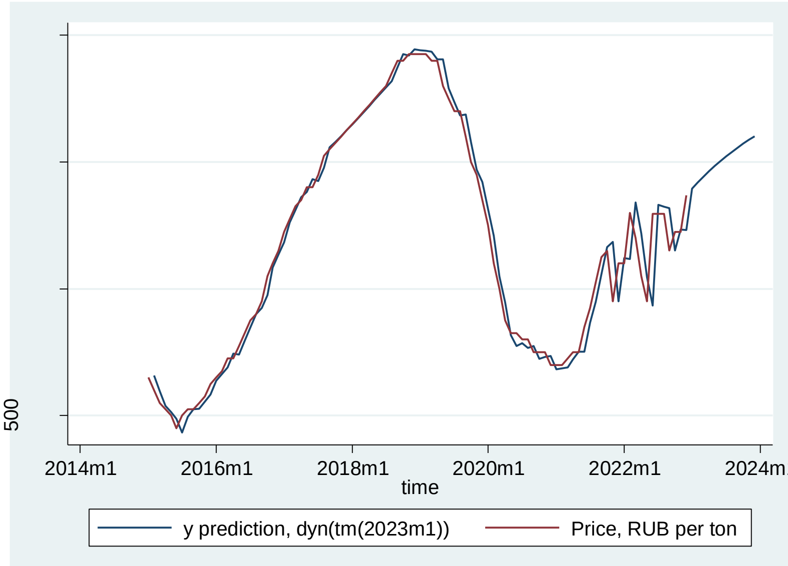

Figure 44. Forecast

Chapter Conclusion

In this chapter, a research model was considered to find the optimal coal transportation route in accordance with a set of criteria.

The key routes for transporting coal from Kuzbass are

- route through the port of Vanino to China,
- through the port of Murmansk to China through the Suez Canal,
- through the port of Taman to China through the Suez Canal.

Also, it is proposed to take into analysis a promising route through the Northern Sea Route, which is supposed to be considered separately in the summer and winter periods.

As a route selection model, the Markowitz optimal portfolio model was chosen, which is used to optimize a securities portfolio, which, unlike the deterministic model, allows taking into account uncertainties for each of the routes. It is worth noting that the compilation of a portfolio of routes by analogy with a securities portfolio is a relatively new technique with little research in this area. Thus, the application of this model is intended to close this research gap in the theory of decision making under conditions of uncertainty in supply chain management.

Also, a model for estimating routes in the above directions is proposed, the results of which are intended to be included in the Markowitz optimization model.

Moreover, the decision-making criteria for choosing the optimal route are considered in addition to the criteria "embedded" in the Markowitz model (cost minimization or risk minimization): these are the "mean-variance" criteria and the VaR criterion, which allows decision makers with different risk appetite to choose desired route.

In accordance with the above criteria, 4 research propositions were formulated. Summary of propositions are presented in the Table 36.

Table 36. Research propositions summary. Source: constructed by the author

№	Research propositions
Research Proposition #1	In the deterministic model, according to the criterion of minimizing the overall logistics costs, all cargo that cannot be sent through the Far East Road must be sent through the Northern Sea Route (both in winter and in summer).
Research Proposition #2	2(a). The expected cost of transporting cargo in winter on the NSR is higher than the expected cost of transporting cargo in summer. 2(b). The volatility of shipping costs in winter on the NSR is greater than the volatility of shipping costs in summer 2(c). Most of the cargo traffic must be sent to the Far East and the Northern Sea Route in summer in accordance to minimization of costs criterion. 2(d). In accordance with the criterion of minimizing risks at a given level of costs, the cargo should not be sent along the northern sea route both in summer and in winter
Research Proposition #3	According to the "mean-variance" criterion, the optimal set of routes includes the transportation through the Northern Sea Route
Research Proposition #4	According to the VAR criterion, the optimal route will be the one in which there is a share of transportation along the Northern Sea Route.

Also, in order to estimate the amount that needs to be invested at a certain planning horizon, if a company wishes to be able to switch to the Northern Sea Route, it was proposed to evaluate this opportunity using the real options method, in particular, using the Margabe asset change option.

At the end of the chapter, the data, data sources, and methods for predicting missing data were described. Also, the data was predicted for the further use in the Markowitz model.

Chapter 4. Case Study Results

This chapter describes the results of calculations of optimization portfolios, route selection criteria, and also estimated a real option to change the route. At the end of the chapter, conclusions for managers are drawn, a discussion is held about the significance of the results for the scientific community, and further research in this area is outlined.

Descriptive statistics

The last preparatory step for constructing the Markowitz model is the final estimate of the cost of transportation along the routes in dollars per ton, taking into account the uncertainty that lies in both prices and days, as well as assessing the risk for each of the routes.

In order to estimate a new random variable that includes both the uncertainty associated with prices and the uncertainty associated with the number of days of delivery of the goods, we will use an approach similar to the simulation approach. To do this, let us estimate what the cost of the freight would be if all the ships on each of the routes would pass consecutively in each of the months of 2023 for which the freight was predicted (Tsoukalas, Kossieris, & Makropoulos, 2020). Then we find the final distribution of the random variable and estimate the risk on each of the routes.

Below is a description of the parameters for multiplying the price and non-price distribution parameters for each of the routes.

Constructed freight cost variable for Vanino route

The distribution of the simulated random variable is shown in the figure. As can be seen from the graph, this distribution has a minimum, a maximum, and a mode. Thus, we will assume that this random variable is distributed according to the triangular distribution law, as well as the random variable describing the number of days of delivery along the route.

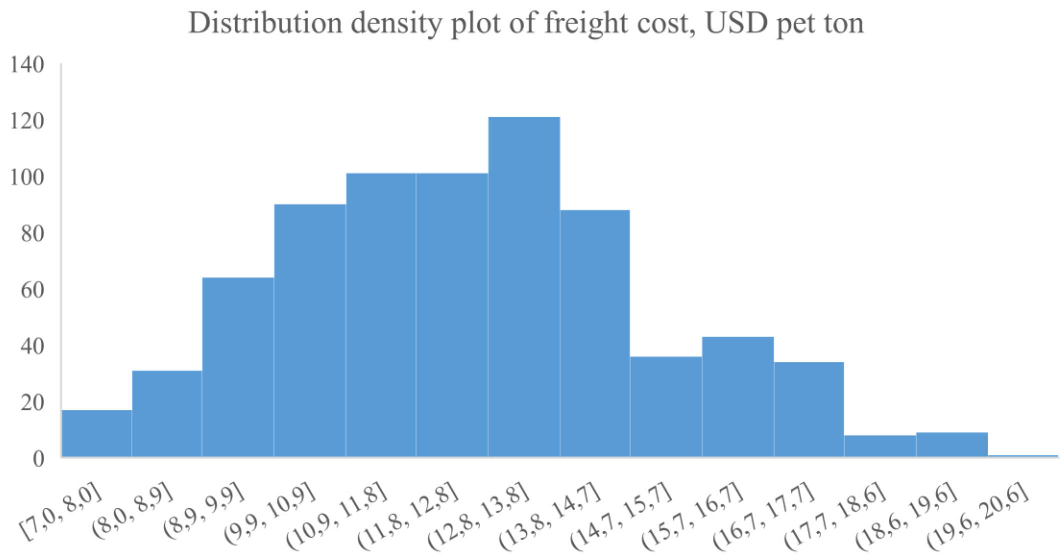

Figure 22. Distribution density plot

The parameters of the current random variable are presented in the Table.

Table 37. Random variable parameters estimation

Parameter	Parameter estimation
Minimum (a)	7.0
Maximum (b)	20.0
Mode (m)	14.3
Expected value (E[X])	13.8
Variance (V[X])	7.1
Standard deviation (σ)	2.7

Constructed freight cost variable for Murmansk through Suez Canal route

The random value of the freight cost, taking into account the number of days, is shown in the figure.

We will assume that this random variable is distributed according to a triangular distribution law.

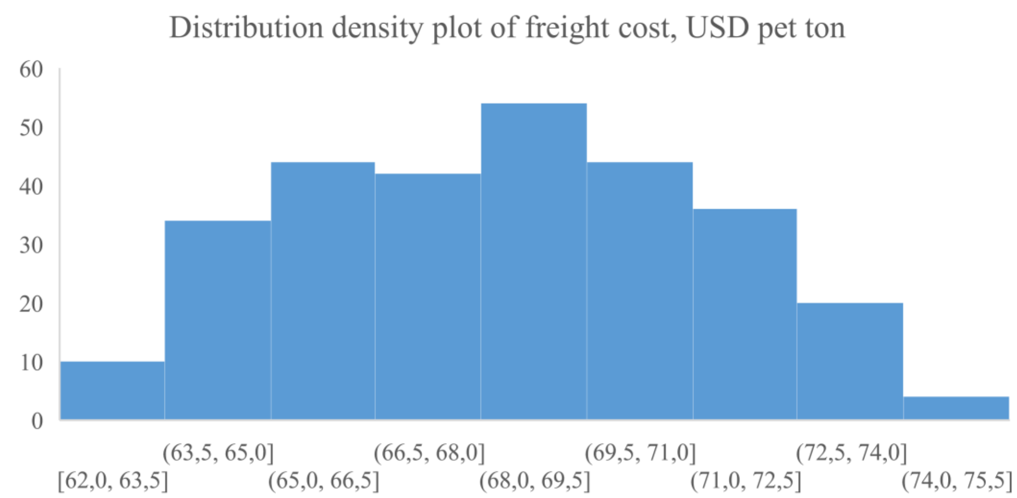

Figure 46. Distribution density plot.

The distribution parameters are presented in the Table 38.

Table 38. Random variable parameters estimation

Parameter	Parameter estimation
Minimum (a)	62.0
Maximum (b)	74.6
Mode (m)	63.3
Expected value (E[X])	66.6
Variance (V[X])	8.0
Standard deviation (σ)	2.8

Constructed freight cost variable for Taman route

The random value of the freight cost from Taman to Guangzhou, taking into account the number of days, is shown in the figure. We will assume that this random variable is distributed according to a triangular distribution law (Fig. 47).

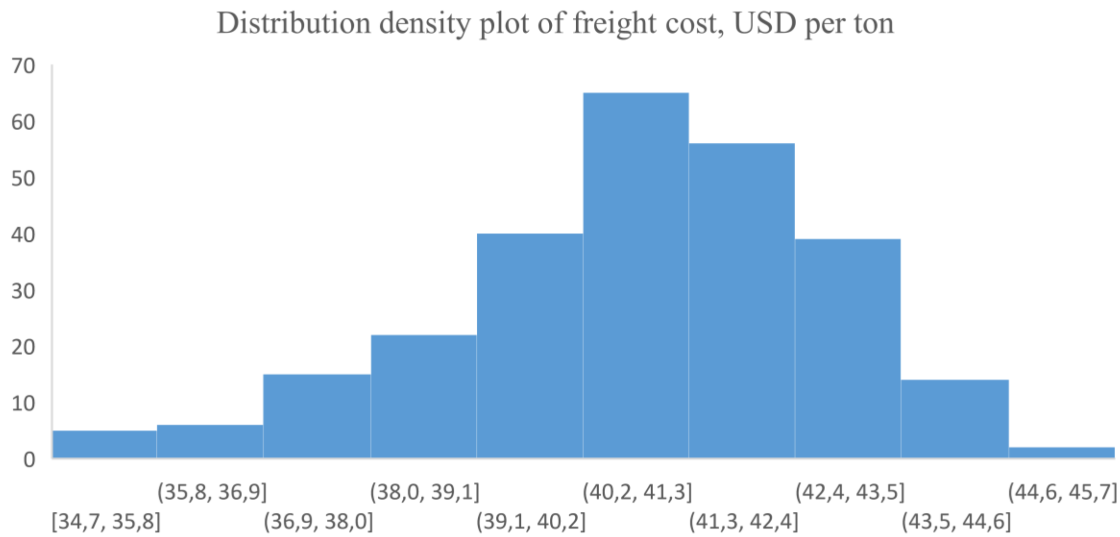

Figure 47. Distribution density plot.

The distribution parameters are presented in the Table 39.

Table 39. Random variable parameters estimation

Parameter	**Parameter estimation**
Minimum (a)	34.7
Maximum (b)	45.1
Mode (m)	39.6
Expected value (E[X])	39.8
Variance (V[X])	4.5
Standard deviation (σ)	2.1

Constructed freight cost variable for Northern Sea Route in summer

The random value of the freight cost from Murmansk through the Northern Sea Route to Guangzhou, taking into account the number of days, is shown in the figure. It would be assumed that this random variable is distributed according to a triangular distribution law, but skewed to the left (Fig. 48).

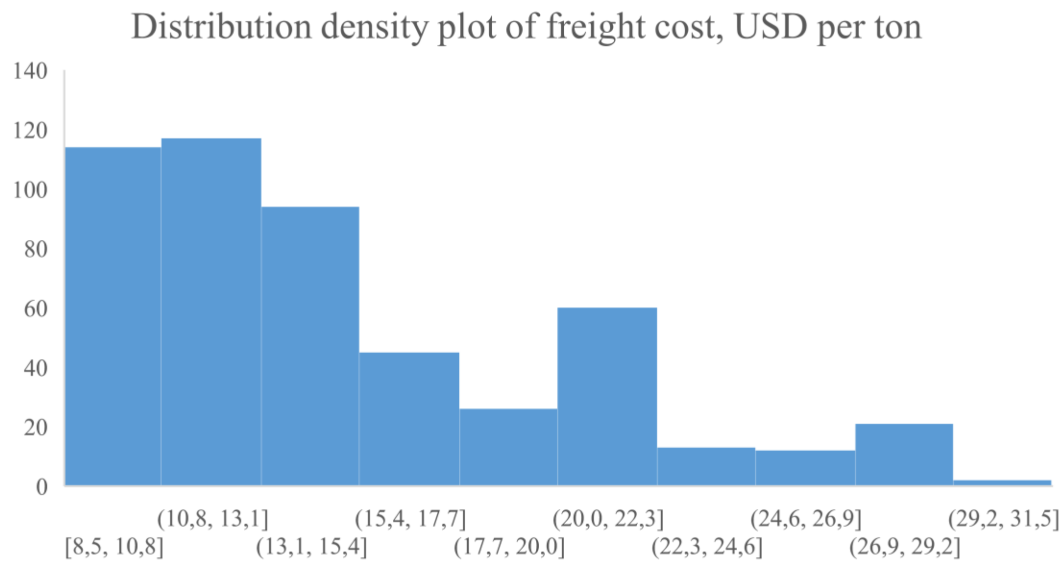

Figure 48. Distribution density plot

The distribution parameters are presented in the Table 40.

Table 40. Random variable parameters estimation

Parameter	**Parameter estimation**
Minimum (a)	8.5
Maximum (b)	29.3
Mode (m)	10.9
Expected value (E[X])	16.2
Variance (V[X])	21.6
Standard deviation (σ)	4.6

Constructed freight cost variable for Northern Sea Route in winter

The random value of the freight cost from Murmansk through the Northern Sea Route to Guangzhou, taking into account the number of days, is shown in the figure. We will assume that this random variable is distributed according to a triangular distribution law, but skewed to the left.

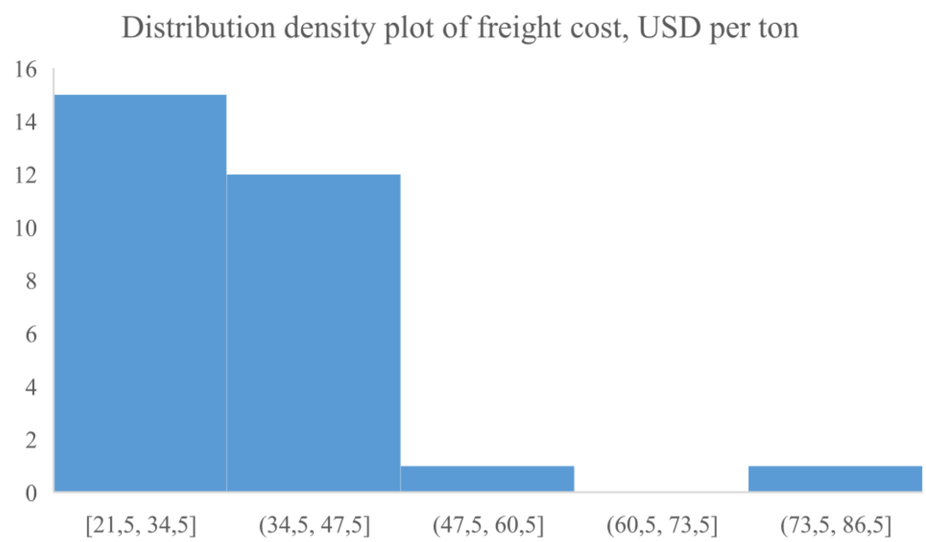

Figure 49. Distribution density plot

The distribution parameters are presented in the Table.

Table 41. Random variable parameters estimation

Parameter	Parameter estimation
Minimum (a)	20.3
Maximum (b)	83.1
Mode (m)	35.5
Expected value (E[X])	46.3
Variance (V[X])	179.4
Standard deviation (σ)	13.4

Transshipment and rail tariffs parameters estimation

To assess the riskiness of price parameters for gondola car rental rates and transshipment rates, we will use the standard deviation indicator, which, according to studies (Kharitonov, 2012; Errais, Bahri, 2015), can be a measure of risk. The standard deviation indicator will be calculated from the monthly data predicted for 2023, and the spread of values (standard deviation) by months during the year will be a risk measure for these indicators.

The final table with estimated risk parameters (standard deviations) and mathematical expectations of tariffs is given in the Table.

Table 42. Estimated risk parameters summary table

Parameter	Transshipment parameters	

	Vanino	Murmansk	Taman	**Rail tariff parameters**
Expected value (E[X])	19.4 USD per ton	13.3 USD per ton	34.8 USD per ton	19.7 USD per day per ton
Standard deviation (σ)	1.09 USD per ton	0.22 USD per ton	0.38 USD per ton	0.89 USD per day per ton

Summary data for Markowitz portfolio construction

Thus, after bringing all the indicators to a common form (in dollars per ton) for the average values for 2023, taking into account all the uncertainties considered in this study (in particular, these are uncertainties in tariffs and uncertainties in the number of days for the delivery of cargo by sea), the following table of parameters is compiled and the total costs are calculated:

Table 43. Estimated parameters summary table

Feature	**Parameter**	**Units**	**Vanino**	**NSR (summer)**	**Murmansk**	**Taman**	**NSR (winter)**
Freight	Expected value (E[X])	USD per ton	13.76	16.23	66.62	39.80	46.28
	Standard deviation (σ)		2.67	4.64	2.82	2.12	13.39
Transshipment	Expected value (E[X])		19.44	13.27	13.27	34.76	13.27
	Standard deviation (σ)		1.09	0.22	0.22	0.38	0.22
Rail tariff	Expected value (E[X])		6.85	11.98	11.98	6.28	11.98
	Standard deviation (σ)		0.31	0.54	0.54	0.28	0.54
Total transportation costs							
Total costs	Expected value (E[X])	USD per ton	40.05	41.48	91.87	80.84	71.54
	Standard deviation (σ)		2.90	4.68	2.88	2.17	13.41

It should be noted that the standard deviation of the total costs is calculated on the assumption that the components of the cost of transportation (freight, transshipment and transportation by rail) are independent random variables.

As can be seen from the table, the mathematical expectation of the cost of the route on the Northern Sor route is higher than in summer (71.5 for the Northern Sea Route in winter and 41.5 in summer). Also, the standard deviation on the Northern Sea Route in winter is almost 3 times greater than the standard deviation of the cost of transportation on the Northern Sea Route in summer, with a difference in the mathematical expectation of less than 2 times. Therefore, Research propositions 2(a) and 2(b), that were stated in Chapter 3, are accepted.

Also, to calculate the standard deviation of the portfolio, it is necessary to calculate the correlation coefficients between these random variables.

The correlation table is presented in Table.

Table 44. Correlation table

	Vanino	**NSR (summer)**	**Murmansk**	**Taman**	**NSR (winter)**
Vanino	1.00	0.39	0.37	-0.03	0.42
NSR (summer)	0.39	1.00	0.54	0.21	0.76
Murmansk	0.37	0.16	1.00	0.41	0.55
Taman	-0.03	0.21	0.41	1.00	0.06
NSR (winter)	0.42	0.76	0.55	0.06	1.00

Deterministic model construction and analysis

The deterministic model was built using the simplex method in the "Solver" package in Excel. The estimated expected costs for the Markowitz portfolio were taken as expected costs.

Table 45. Deterministic model results

	Vanino	**NSR (summer)**	**Murmansk**	**Taman**	**NSR (winter)**	**Total costs**
Expected transportation costs	40,0	41,5	91,9	80,8	71,5	N/A
Volume of coal transportation for case	4 000 000	6 000 000	-	-	-	409 mln USD

without restrictions						
Volume of coal transportation for case with restrictions	4 000 000	3 000 000	-	-	3 000 000	499 mln USD

The result of the calculation turned out to be quite obvious: since the only restriction on the route is the volume of transportation, the weights along the routes were distributed in accordance with which route is the cheapest: for the model without restrictions on transportation along the NSR in summer, it turned out that 4 million tons must be transported through Vanino , and the rest along the NSR in the summer. And with the limitation of transportation along the NSR in the summer with a volume of 3 million tons, the model distributes the weight of the routes in ascending order of unit costs: 40% in Vanino, 30% along the NSR in summer, and the remaining 30% along the NSR in winter.

Therefore, the Research Proposition 1 is accepted.

Markowitz portfolio construction and analysis

This section discusses the results of constructing the Markowitz model and the application of criteria for choosing the optimal route

Portfolio construction results

To compile the Markowitz portfolio, the following assumptions were made: the company wants to ship 10 million tons of coal in 2023, while it has a limit of 4 million tons for shipment via the Eastern route: that is, it will not be able to transport more than 4 million tons.

Next, a set of routes was compiled: at a given level of costs, the standard deviation of the portfolio was minimized. This task was solved using the add-in Solver in Excel. A screenshot of the specified parameters for solving this problem is presented in the Appendix 12.

Case without restrictions on the NSR in the summer

Let us first consider the case under the assumption that the company can transport along the Northern Sea Route in summer as much as it needs.

A route distribution was found for each cost level from $40.9 per ton to $65 per ton in increments of $1 per ton. The results of the calculation of each of the steps are presented in the Table 46.

Table 46. Results of portfolios construction

Share of cargo traffic in the portfolio of routes, %	Parameters

Vanino	NSR (summer)	Murmansk	Taman	NSR (winter)	Expected costs, USD per ton	Variance	Standard deviation
38.8%	-	-	61.2%	-	65	2.94	1.71
40.0%	1.3%	-	58.7%	-	64	2.97	1.72
40.0%	3.9%	-	56.1%	-	63	3.03	1.74
40.0%	6.4%	-	53.6%	-	62	3.12	1.77
40.0%	8.9%	-	51.1%	-	61	3.24	1.80
40.0%	11.5%	-	48.5%	-	60	3.39	1.84
40.0%	14.0%	-	46.0%	-	59	3.56	1.89
40.0%	16.6%	-	43.4%	-	58	3.77	1.94
40.0%	19.1%	-	40.9%	-	57	4.00	2.00
40.0%	21.7%	-	38.3%	-	56	4.26	2.07
40.0%	24.2%	-	35.8%	-	55	4.56	2.13
40.0%	26.7%	-	33.3%	-	54	4.88	2.21
40.0%	29.3%	-	30.7%	-	53	5.23	2.29
40.0%	31.8%	-	28.2%	-	52	5.61	2.37
40.0%	34.4%	-	25.6%	-	51	6.02	2.45
40.0%	36.9%	-	23.1%	-	50	6.45	2.54
40.0%	39.4%	-	20.6%	-	49	6.92	2.63
40.0%	42.0%	-	18.0%	-	48	7.41	2.72
40.0%	44.5%	-	15.5%	-	47	7.94	2.82
40.0%	47.1%	-	12.9%	-	46	8.49	2.91
40.0%	49.6%	-	10.4%	-	45	9.07	3.01
40.0%	52.1%	-	7.9%	-	44	9.68	3.11
40.0%	54.7%	-	5.3%	-	43	10.32	3.21
40.0%	57.2%	-	2.8%	-	42	10.99	3.32
40.0%	60.0%	-	-	-	41	11.69	3.42

In the Figure 50 below, the effective Markowitz frontier is constructed, and the fractions of routes that do not fall within the effective Markowitz frontier are randomly generated.

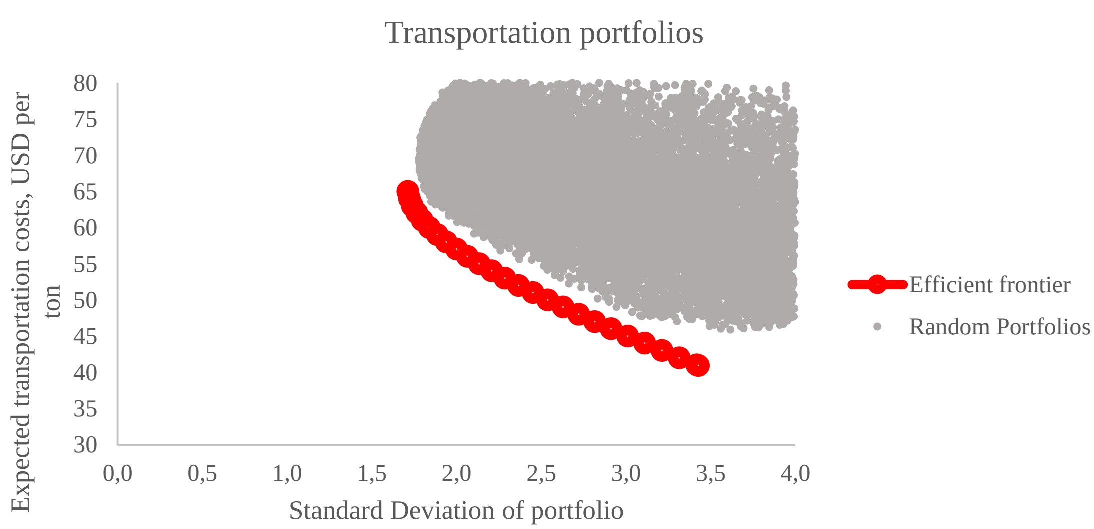

Figure 50. Transportation portfolios graph

Table shows that if the decision maker wants to minimize costs by any means, the company must send all cargo through Vanino and the Northern Sea Route in the summer. Thus, Research Proposition 2(c) is accepted.

At the same time, when the company is ready to pay any money, but is not at all ready to take risks, there is no share of the Northern Sea Route in the route portfolio at all. Thus, Research Proposition 2(d) is accepted.

Case with restrictions on the NSR in the summer

As can be seen from the analysis, the Northern Sea Route in winter is of no interest to the company: there is not a single portfolio of routes lying on the effective border, which would include at least some volume of shipments along the Northern Sea Route in winter.

However, the summer shipping period along the Northern Sea Route is quite short. Therefore, it makes sense to put a limit on the volume of sending on this route. Let us assume that the maximum possible volume of transportation along the Northern Sea Route in the summer period is limited to 3 million tons. Then the table and chart with effective portfolio frontier look like this (Table 47 and Figure 51):

Table 47. Results of portfolios construction

Share of cargo traffic in the portfolio of routes, %					**Parameters**		
Vanino	NSR (summer)	Murmansk	Taman	NSR (winter)	Expected costs, USD per ton	Variance	Standard deviation
36,8%	-	1,4%	61,8%	-	66	2,93	1,71
38,8%	-	-	61,2%	-	65	2,94	1,71
40,0%	1,3%	-	58,7%	-	64	2,97	1,72
40,0%	3,9%	-	56,1%	-	63	3,03	1,74
40,0%	6,4%	-	53,6%	-	62	3,12	1,77
40,0%	8,9%	-	51,1%	-	61	3,23	1,80
40,0%	11,5%	-	48,5%	-	60	3,39	1,84
40,0%	14,0%	-	46,0%	-	59	3,56	1,89
40,0%	16,6%	-	43,4%	-	58	3,77	1,94
40,0%	19,1%	-	40,9%	-	57	4,00	2,00
40,0%	21,7%	-	38,3%	-	56	4,26	2,07
40,0%	24,2%	-	35,8%	-	55	4,56	2,13
40,0%	26,7%	-	33,3%	-	54	4,88	2,21
40,0%	29,3%	-	30,7%	-	53	5,23	2,29
40,0%	30,0%	-	27,7%	2,3%	52,5	6,33	2,52
40,0%	30,0%	-	22,3%	7,7%	52	9,40	3,07
40,0%	30,0%	-	11,5%	18,4%	51	18,67	4,32
40,0%	30,0%	-	0,8%	29,2%	50	32,12	5,67
40,0%	30,0%	-	0,0%	30,0%	49,9	33,28	5,77

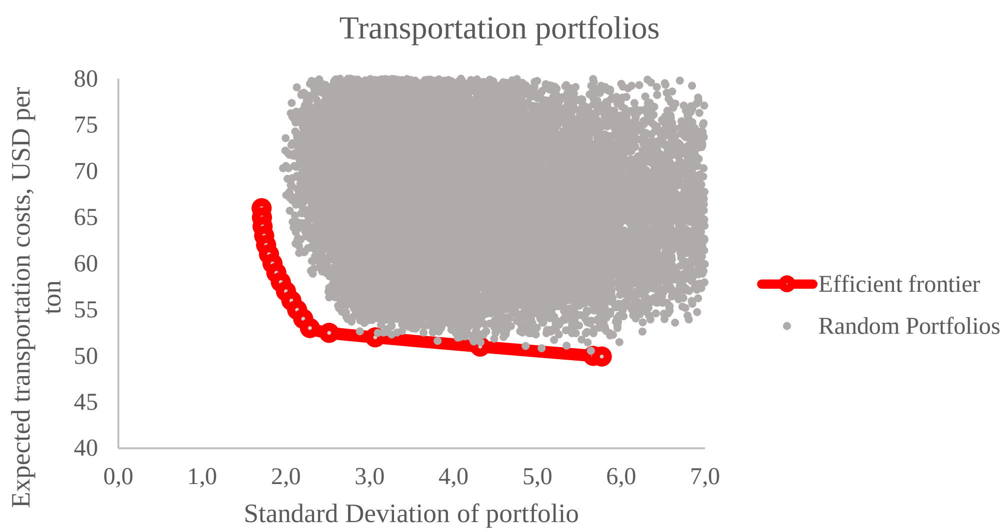

Figure 51. Transportation portfolios graph

As can be seen from the table, taking into account such a limitation, shipments along the northern sea route in winter have already begun to be included in the portfolio of optimal routes, albeit in a small percentage. However, from the point of view of minimizing costs, this route wins over shipments to Taman.

Criteria for route choice

Two decision criteria were considered to select the optimal route: the "mean-variance" criterion and the VAR criterion. Both criteria were calculated for each of the portfolios lying on the efficient frontier. The calculation results for these criteria are presented in the Table 48.

Table 48. Route choice criteria

Share of cargo traffic in the portfolio of routes, %					**Portfolio choice criteria**	
Vanino	NSR (summer)	Murmansk	Taman	NSR (winter)	Mean-Variance criterion	VaR criterion
38,8%	-	-	61,2%	-	37,91	67,76
40,0%	1,3%	-	58,7%	-	37,14	67,55
40,0%	3,9%	-	56,1%	-	36,19	65,57
40,0%	6,4%	-	53,6%	-	35,10	65,33
40,0%	8,9%	-	51,1%	-	33,90	63,38
40,0%	11,5%	-	48,5%	-	32,61	63,17
40,0%	14,0%	-	46,0%	-	31,26	61,26
40,0%	16,6%	-	43,4%	-	29,88	61,08
40,0%	19,1%	-	40,9%	-	28,50	59,23
40,0%	21,7%	-	38,3%	-	27,12	59,07
40,0%	24,2%	-	35,8%	-	25,76	57,26
40,0%	26,7%	-	33,3%	-	24,45	57,14
40,0%	29,3%	-	30,7%	-	23,18	55,35
40,0%	31,8%	-	28,2%	-	21,96	55,26
40,0%	34,4%	-	25,6%	-	20,79	53,49

40,0%	36,9%	-	23,1%	-	19,68	53,42
40,0%	39,4%	-	20,6%	-	18,63	51,65
40,0%	42,0%	-	18,0%	-	17,63	51,59
40,0%	44,5%	-	15,5%	-	16,68	49,84
40,0%	47,1%	-	12,9%	-	15,79	49,77
40,0%	49,6%	-	10,4%	-	14,94	48,00
40,0%	52,1%	-	7,9%	-	14,14	47,98
40,0%	54,7%	-	5,3%	-	13,38	46,14
40,0%	57,2%	-	2,8%	-	12,67	46,16
40,0%	60,0%	-	-	-	11,99	44,18

Two decision criteria were considered to select the optimal route: the "mean-variance" criterion and the VAR criterion. Both criteria were calculated for each of the portfolios lying on the efficient frontier. The calculation results for these criteria are presented in the table.

According to both criteria, it is necessary to choose the smallest indicator: the "mean-variance" criterion shows how much the cost of transporting the path falls on 1 conventional unit of the assessed risk. At the same time, the VAR criterion shows how much the costs for the total portfolio will not rise above in 95% of cases.

The lowest performance for both criteria has a route with 40% distribution in Vanino and 60% distribution along the Northern Sea Route in the summer.

Thus, Research Propositions 3 and 4 are accepted.

Real Option valuation results

Real options analysis allows a coal exporting company to answer the question: how much should be invested in the development of a particular route in order to be able to switch to it from one of the current routes after a certain period of time. We will conduct this analysis in the context of the possibility of switching from each of the existing routes (Vanino, Taman and Murmansk) to the Northern Sea Route both in summer and in winter (considered separately, as in the rest of this study).

Table 45 shows the calculation of the parameters for estimating the real Margabe option. The cost of a real option is given at the rate of $1 per ton of transported cargo.

Table 49. Margabe options calculations results

Route to change	**Vanino**		**Taman**		**Murmansk**	
New route	**NSR summer**	**NSR winter**	**NSR summer**	**NSR winter**	**NSR summer**	**NSR winter**
Transportation costs for the old route (U_0)	-40,0	-40,0	-80,8	-80,8	-91,87	-91,87
Transportation costs for the new route (V_0)	-41,5	-71,54	-41,5	-71,54	-41,5	-71,54
Correlation coefficient (ρ)	0,39	0,42	0,21	0,06	0,16	0,55

Volatility of old route (σ_U)	7%	7%	3%	3%	3%	3%
Volatility of new route (σ_V)	11%	19%	11%	19%	11%	19%
T	5	5	5	5	5	5
$\hat{\sigma}$	11%	17%	11%	19%	11%	17%
d_1	0,27	1,72	-2,58	-0,08	-3,04	-0,46
d_2	0,03	1,34	-2,83	-0,50	-3,29	-0,84
$N(d_1)$	0,61	0,96	0,00	0,47	0,00	0,32
$N(d_2)$	0,51	0,91	0,00	0,31	0,00	0,20
Option Value	-4,67	-32,04	-0,01	-8,53	0,00	-4,80

Analyzing the results of calculating Margabe options, it is important to note that in the original work, Margabe assessed the possibility of exchanging assets, while at the same time, in the current work, the possibility of exchanging liabilities is estimated: in fact, the possibility of exchanging one cost for another is assessed. Thus, when calculating option values, a positive value cannot be obtained here, and in this case, the option value will be interpreted not as a gain from a potential asset exchange, but as costs that a company can incur when exchanging one route for another, and these values are not can be greater than 0 (and all option values will be less than or equal to 0).

As can be seen from the analysis, for two routes it makes sense to consider switching to the summer period of navigation along the Northern Sea Route: from Murmansk and from Taman, since the values of the options are close to 0 (that is, the cost in dollars per ton for obtaining potential transportation benefits). At the same time, the cost of switching from Vanino to the Northern Sea Route in winter costs about $32 per ton, which is a huge value compared to the cost of transportation.

It is worth mentioning here the limitation of the real options method applied in this study: since the classic Margabe option is a European option (that is, it is an option that can only be exercised on the last day of its expiration), it shows how much should be invested in development paths with a complete switching of the cargo flow and only at a specific point in time (in T years). However, in real life, things can be different: the company most likely wants to be able to switch not exactly in T years, but at some point in time (before the option's expiration date). Thus, as a further research, it is possible to consider an American option. Also, this study is one of the few on the topic of real options analysis, which analyzes the cost of exchanging not assets, but costs. As a further study, more in-depth research needs to be done to analyze the switching cost and interpret this cost when calculating real options.

Discussion

The purpose of this section is to provide a summary of the findings and to discuss the academic and practical implications of the study.

Summary of results

Research question for this paper is: "which routes to choose to export coal, taking into account possible uncertainties?" To sum up, 4 possible routes (through Vanino port, Taman port, the port of Murmansk through the Suez Canal and the Northern Sea Route in division to summer and winter periods of navigation) were analyzed through the perspective of propositions stated in "Research methodology" chapter in this working paper and the answer to the research question for each transportation route was obtained. The table below contains a summary of the properties of each of them:

Table 50. Parameters summary table

Feature	Parameter	Units	Vanino	NSR (summer)	Murmansk	Taman	NSR (winter)
Total costs	Expected value (E[X])	USD per ton	40.05	41.48	91.87	80.84	71.54
	Standard deviation (σ)		2.90	4.68	2.88	2.17	13.41

Also, a summary table for testing research propositions is presented in the table below:

Table 51. Propositions summary table

№	**Research propositions**	**Research propositions testing results**
Research Proposition #1	In the deterministic model, according to the criterion of minimizing the overall logistics costs, all cargo that cannot be sent through the Far East Road must be sent through the Northern Sea Route (both in winter and in summer).	Accepted
Research Proposition #2	2(a). The expected cost of transporting cargo in winter on the NSR is higher than the expected cost of transporting cargo in summer.	Accepted

	2(b). The volatility of shipping costs in winter on the NSR is greater than the volatility of shipping costs in summer	Accepted
	2(c). Most of the cargo traffic must be sent to the Far East and the Northern Sea Route in summer in accordance to minimization of costs criterion.	Accepted
	2(d). In accordance with the criterion of minimizing risks at a given level of costs, the cargo should not be sent along the northern sea route both in summer and in winter	Accepted
Research Proposition #3	According to the "mean-variance" criterion, the optimal set of routes includes the transportation through the Northern Sea Route	Accepted
Research Proposition #4	According to the VAR criterion, the optimal route will be the one in which there is a share of transportation along the Northern Sea Route.	Accepted

Academic implications

On the theoretical side, this study aims to close research gaps in two areas: first, it aims to propose a methodology for making decisions under uncertainty in supply chain management, using the well-known Markowitz portfolio construction method in finance. In the academic literature, although there are some articles on this topic that prove the applicability of this method, they are still not enough. Also, the Markowitz portfolio is supplemented with two decision criteria, which allows to choose the route for decision makers with different appetite to risk.

Moreover, this study has shown that the use of real option methods is easy to apply in practice and allows decision makers to assess the need for investment for opportunities to switch between routes.

The second area in which my research is aimed to close research gaps is the area of research on the risks of the Northern Sea Route. Many attempts have been made to calculate the cost of transportation along the Northern Sea Route in comparison with alternative routes, however, there is not a single study that would evaluate not just the possibility of getting stuck in ice, but in general the expected value of cargo delivery along this route and the volatility of the value of shipping costs along this route on real data, especially in the division into winter and summer periods.

Practical implications

From a practical point of view, this research paper is of value primarily for Russian coal exporting companies that do not have their own captive terminals in ports and their own fleet and who work with others in the industry on market terms (that is, those who are subject to market transshipment rates and freight rates). For them, this study allows answering the question of whether it is worth investing in the development of their own Arctic-class bulk carrier fleet and the construction of port infrastructure along the Northern Sea Route. This study shows that in order to be able to switch to the northern sea route in 5 years from current routes (except Vanino), it is necessary to invest from 17 to 50 dollars per ton of cargo transported in infrastructure development and building a fleet of a suitable Arctic class for transportation along northern sea route.

Also, this study is also useful for large coal companies that have their own transshipment capacities (and who ship on non-market conditions in ports): this model is flexible and allows company to change the parameters of each of the elements of the route to those used by the company.

Moreover, potential users of this study may be decision makers on investments in the development of the Northern Sea Route: port operators, shipbuilding companies and the Government. For port operators and shipbuilders, this study also highlights the promise of the Northern Sea Route, which coal companies can switch to, allowing them to plan their production capacity to meet the needs of potentially increased demand in the next 5 years on the Northern Sea Route. For the Government, this study will be useful, because it also emphasizes the prospects of the Northern Sea Route in the summer, which will make it possible to make decisions on subsidizing industries related to the provision of this route.

However, this study also shows that the route to Vanino is still the least risky and cheapest, highlighting the importance of widening the bottlenecks of the Far East road, and Russian Railways may be the beneficiary of this conclusion.

Limitations and further research directions

This section focuses on examining the limitations of this paper and proposing potential directions for future research.

The first limitation of this study is the limited number of routes: only 3 Russian ports and 1 Chinese port are considered in the study, and, accordingly, data are taken only for these routes (both data on the cost of tariffs and on the number of days of transportation). Then it could be very useful for the study to add more ports in China and Russia in order to increase the sample in the first place by the number of days of delivery, and clarify the price characteristics. Moreover, in the current study, data were taken only for ships of 100-110 thousand dwt, which refers to Post-Panamax ships. Other types of vessels could be added to make the analysis more complete.

The third limitation of the current study is that it does not take into account transaction costs: for cargo clearance, for example.

Also, in the current study, the number of days of delivery by rail was taken as a constant. However, this condition is not always met, since there are delays on the railway as well[51]. This study can be strengthened by another uncertainty related to the number of days of transportation by rail.

The fifth limitation of this study is the limitation associated with the assumptions of the calculations: for example, to estimate the number of days along the Northern Sea way from Cape Dezhnev to Gunazhou, the constant was taken as the number of days required to get there. However, there may also be uncertainties on this section of the route (which is confirmed by the fact that there is a fairly large spread in the values of the number of days from Vanino to Guangzhou).

Sixth, this study does not take into account other restrictions on Northern Sea Route transportation, such as lack of infrastructure, lack of icebreakers, and lack of a suitable Arctic-class fleet. As a future study, it would be possible to conduct studies on the adequacy of shipbuilding capacities (both in Russia and abroad) and compare these data with the current study, as well as conduct scenario planning for the development of the shipbuilding industry (and the launch of new ships and icebreakers in the NSR water area) with taking into account current inputs.

Also, it is worth noting that the parameters for building the Markowitz model are taken as a model example: for example, the maximum volume of traffic through the port of Vanino is taken as a model assumption. Thus, this study can be strengthened by more real data of specific companies.

[51] Niu, W.; Wang, X. (2018). Risk evaluation of railway coal transportation network based on Multi Level Grey Evaluation Model. IOP Conference Series: Earth and Environmental Science, 108, 042108. https://doi.org/10.1088/1755-1315/108/4/042108

Chapter Conclusion

This chapter describes the results of calculating a deterministic route selection model, a stochastic route selection model (the Markowitz model was chosen as a model form for a portfolio of routes by analogy with a portfolio of financial instruments), consisting of transportation through Vanino, the Southern Sea Route (through the ports of Murmansk and Taman) and through the Northern Sea Route (summer and winter navigation periods are considered separately). Also, the criteria for choosing the optimal route are calculated: the "mean-variance" criterion and the VAR criterion, which is widely used in risk management. Despite the fact that shipping along the Northern Sea Route is the riskiest option of all proposed (with the highest standard deviation for the total costs per route), according to both of the above criteria, the optimal portfolio of the Markowitz model will be the route according to which the entire volume of traffic, who will not be able to go on the route to Vanino, should go along the Northern Sea Route in the summer.

Moreover, a case was considered with the restriction of transportation along the Northern Sea Route during the summer navigation period, caused by the assumption that the summer navigation period along the Northern Sea Route is quite limited in time. It was found that even taking into account this limitation, the optimal portfolio will be a portfolio that contains, in addition to the maximum possible transportation to Vanino, a route through the Northern Sea Route in winter.

At the end, the option to switch between each of the current routes to the route of the Northern Sea Route according to the Margabe model was evaluated. An analysis of real options showed that it makes no sense to switch from Vanino to the Northern Sea Route. However, switching from other routes has its value, and the analysis of real options showed what amount of investments in terms of dollars per ton of transported cargo can be done now in order to be able to switch to the NSR route in 5 years (both in winter and in summer).

Conclusion

This was aimed to answer the question of how to choose a route for transporting goods, taking into account not only the cost of transportation, but also uncertainties, encountered on routes. In particular, the case of transporting Russian coal for export to China was considered: a comparison was made between the current transportation routes and a potential route through the Northern Sea Route.

The route through the Northern Sea Route is a route that, despite the active support from the state and its cheapness of the relatively often compared Southern Sea Route (via the Suez Canal from the ports of Murmansk and Taman), is still not commercial. One of the key reasons is the uncertainties associated with the timing of cargo delivery along this route, which can significantly increase the cost of transportation.

Thus, transportation costs for 2023 were estimated for ships of 100 thousand dwt on the above routes, taking into account the uncertainty of delivery days according to data taken from professional sources: Argus, AXS Dry, Clarkson, industrial and company reports, as well as statistics from website of the Administration of the Northern Sea Route.

Although the Northern Sea Route is deemed the riskiest option among the proposed routes, with the highest standard deviation for total costs per route, it satisfies both criteria in the Markowitz model for an optimal portfolio. Therefore, during the summer season, it is recommended that the entire volume of traffic which cannot take the route to Vanino should be directed to the Northern Sea Route.

On the theoretical side, the objective of this study was to fill the gaps in research in two areas. Firstly, it aimed to propose a methodology using the Markowitz portfolio construction method from finance to make decisions under uncertainty in supply chain management. Although some research papers have proven its applicability in this field, they are still insufficient. Additionally, my proposal supplements the Markowitz portfolio with two decision criteria, enabling decision makers to choose their preferred path based on their risk appetite. Hence, my study proves that real option methods are easy to apply in practical situations and aid decision makers in assessing investment needs for opportunities to switch between routes. Secondly, my research aims to fill the research gaps in the subject of Northern Sea Route risks. Although previous studies have attempted to calculate the cost of transportation along the route in comparison to alternative routes, none of them have evaluated the expected value of cargo delivery with the volatility of shipping cost value using real data. My study seeks to bridge this research gap, particularly focusing on the winter and summer periods.

This research paper offers practical value mainly for Russian coal exporters who do not possess their own ports or fleet and who conduct business under market transshipment rates and freight rates. For these companies, the research can assist in determining whether to invest in their own fleet of Arctic-class bulk carriers and developing port infrastructure along the Northern Sea Route.

Large coal companies with their own transshipment capacities may also benefit from this study, as the model is flexible and can adapt to the parameters used by the company. Furthermore, decision-makers in port operations, shipbuilding, and the government may also find this study useful. For port operators and shipbuilders, the research emphasizes the potential of the Northern Sea Route, giving them an opportunity to plan their resources for potentially increased demand in the next five years. The study also highlights the Northern Sea Route's prospects in summer, allowing the government to make decisions on subsidizing industries related to this route. Finally, the research warns that the route to Vanino remains the least risky and cheapest, underscoring the need to widen the bottlenecks of the Far East road, with Russian Railways likely benefiting from this conclusion.

The first limitation of this study is the limited number of routes, with only 3 Russian ports and 1 Chinese port being considered. To increase the sample size and gain more clarity on the price characteristics, it would be beneficial to add more ports in both China and Russia. Furthermore, the data used in this study is only for ships of 100-110 thousand dwt (Post-Panamax ships), so adding other types of vessels would make the analysis more comprehensive. The third limitation is that it does not take into account transaction costs such as cargo clearance. Additionally, the number of days of delivery by rail was taken as a constant, but this is not always the case due to delays. To improve this study, another uncertainty could be included related to the number of days of transportation by rail. The present study has limitations related to assumptions made about the constant number of days for delivery by rail, uncertainties associated with estimating the duration of travel along the Northern Sea Route, and not considering other constraints on transportation such as inadequate infrastructure and insufficient icebreakers. Future studies could investigate shipbuilding capacities and conduct scenario planning for the development of the shipbuilding industry, while also incorporating more realistic data from specific companies to strengthen the Markowitz model used in this study.

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Appendix

Appendix 1

Table 52. Types of bulker vessels by deadweight. Source: Marine Construction Technologies site

Type of bulker vessel	Deadweight, tons	Description
Coasters	Less than 15 000	Ship carrying out commercial trade within one state
Handysize	15 000 – 40 000	Handysize ships are considered the most common because they allow entry into small ports, and in most cases they are equipped with cranes to unload cargo themselves. Compared to large bulk carriers, Handysize ships handle more extensive handling of so-called "piece" cargo. These include: steel products, grain, phosphates, wood, crushed stone. Handysize ships are considered the most common because they allow entry into small ports, and in most cases they are equipped with cranes to unload cargo themselves. Compared to large bulk carriers, Handysize ships handle more extensive handling of so-called "piece" cargo. These include: steel products, grain, phosphates, timber, crushed stone. The most common standard in this category of ships are bulk carriers with a deadweight of about 32,000 tons and a draft of not more than 10 m. They have five cargo holds with hydraulic tween decks, and four cranes for handling cargo. Some Handysize ships are equipped with racks on the upper deck, between which timber is stacked, for which they are called "timber carriers". Despite numerous orders from shipping companies for new types of vessels, Handysize remains the most sought after and has the highest average age among bulk carriers.

Handymax	40 000 – 50 000	Vessels of this type have a length of 150-200 m and are equipped with 5 cargo holds. As a rule, these are older vessels. Modern bulk carriers already have a deadweight of 52,000 to 58,000 tons and are equipped with 5 cargo holds and equipped with 4 cranes with a lifting capacity of up to 30 tons each.
Supramax (Large Handymax)	50 000 – 60 000	Bulk carriers of Supramax size, which are gradually replacing Handymax ships, range from 50,000 dwt to 60,000 dwt. Like their predecessors, they also have 5 cargo holds.
Ultramax	60 000 – 65 000	Their distinguishing feature is not the size, but the environmentally friendly main engine. Ultramax bulk carriers are considered upgrades to Supramax ships and are equipped with five cargo holds. So far, this is a small fleet.
Seawaymax	60 000 – 100 000	The term "Seawaymax" refers to ships that can pass through the St. Lawrence Canal, the name of the waterway from Montreal to Lake Erie, including the Welland Canal and the Great Lakes waterway from the Atlantic Ocean to the Great Lakes in North America.
Kamsarmax	80 000 – 85 000	The most common design with a deadweight of 82,000 tons. The length of such dry cargo ships is 229 m, width 32 m and draft 14.5 m, which is the maximum allowable parameter for entering the port of Kamsar, Guinea in West Africa, one of the largest bauxite transshipment ports in the world.
Panamax	60 000 – 80 000	Panamax size bulk carriers are limited by the parameters of the Panama Canal locks.
Post-Panamax	90 000 – 110 000	The term is applied to modern Post-Panamax size bulk carriers, which are 240m long and 38m wide, 6m wider than the Panama Canal lock chambers. Due to this characteristic, they cannot pass this canal.

Capesize	160 000 – 210 000	The term "Capesize" refers to cargo ships that, due to their large size, are not able to pass through the Suez and Panama canals. In English, the word "cape" means "cape". Thus, ships of this type should pass along the Cape of Good Hope in the south of the African continent or Cape Horn - the southernmost point of South America. The main bulk carriers of this size are large grain carriers and ore carriers with an average deadweight of 175,000 tons, a hull length of 289 m, a width of 45 m, a draft of 17.9 m and have 9 cargo holds. Some "Capesize" with a maximum width of 47m are called "Newcastlemax" and are the largest ships that can call at the port of Newcastle in Australia.
Valemax (ULOC — Ultra Large Ore Carrier)	~ 400 000	China's economic growth, with its strong demand for raw materials, has led to a need to increase Capesize ships. This is how ultra-large ore carriers with a deadweight of 400,000 tons, a length of 362 m, a width of 65 m and a draft of 23 m were born. The largest vessels in this category are the Valemax series, plying with a cargo of iron ore between the ports of Brazil and China. Vessels of this size are handled at specialized deep water terminals.

Appendix 2

Table 53. Coal vessels ship calls from Vanino to Guangzhou in 2015-2021. Source: AXS Dry database

Vessel	Departure Date	Arrival Date	Volume intake	Voyage days
Genco Freedom	19.11.2015	30.11.2015	69 080	11
CMB Teniers	05.03.2015	16.03.2015	86 116	11
Common Galaxy	02.11.2016	14.11.2016	74 094	12
Spring Oasis	05.12.2016	14.12.2016	77 204	9
Pan Poseidon	21.05.2016	30.05.2016	62 766	9
Gloria Confidence	09.09.2016	21.09.2016	99 404	12

MH Arpeggio	26.05.2017	06.06.2017	63 231	11
Ultra Integrity	28.05.2017	06.06.2017	51 340	9
Acer Arrow	23.10.2017	03.11.2017	98 636	11
Unity Explorer	09.04.2017	20.04.2017	51 569	11
STH Oslo	12.06.2017	21.06.2017	93 114	9
Consolidator	06.10.2017	15.10.2017	52 889	9
NORD NEPTUNE	19.02.2018	28.02.2018	64 367	9
LUNI	21.03.2018	01.04.2018	69 834	11
JIN SHAN	19.05.2019	02.06.2019	53 890	14
SILVER LADY	14.05.2019	28.05.2019	48 138	14
ABIGAIL	27.05.2019	09.06.2019	57 631	13
GLORY TRADER	18.02.2019	04.03.2019	74 562	14
GIORGAKIS	08.01.2019	21.01.2019	77 120	13
FIDELITY	26.08.2019	08.09.2019	77 326	13
DL ADONIS	08.01.2019	22.01.2019	73 606	14
LILA SEOUL	08.12.2019	18.12.2019	74 477	10
New Endeavor	22.08.2019	03.09.2019	71 544	12
INDIAN SOLIDARITY	21.04.2019	30.04.2019	67 858	9
BASIC PRINCESS	24.11.2019	08.12.2019	88 176	14
PERSEAS	03.07.2019	16.07.2019	72 078	13
SITC HENGSHAN	06.08.2019	17.08.2019	72 156	11
NORD PENGUIN	01.01.2019	12.01.2019	73 657	11
Prt Kaho	06.11.2019	17.11.2019	71 686	11
DARYA KRISHNA	16.10.2019	24.10.2019	31 583	8
DUKE	02.10.2020	13.10.2020	43 380	11
NANXIN ANGELA	27.05.2020	10.06.2020	70 373	14
JIAN FA	25.10.2020	07.11.2020	64 488	13
CNA 5	21.05.2020	01.06.2020	30 230	11
BROAD RICH	27.04.2020	10.05.2020	66 488	13
TEMPO LOONG	13.05.2020	24.05.2020	68 195	11
Knossos Wave	12.07.2020	25.07.2020	75 979	13
TREASURE STAR	28.05.2020	07.06.2020	77 105	10
Kambanos	16.10.2020	27.10.2020	76 271	11
ALBERT OLDENDORFF	07.02.2020	19.02.2020	76 427	12
SANTA EMILIA	04.04.2020	14.04.2020	72 480	10
COMMON LUCK	18.03.2020	29.03.2020	50 567	11
DL Carnation	10.06.2020	22.06.2020	75 294	12
GLOBAL ORIOLE	19.02.2020	01.03.2020	52 698	11
TUO FU 8	25.08.2020	05.09.2020	77 670	11
ELECTRA	22.12.2020	06.01.2021	78 060	15
FIRST ANGELUS	15.10.2020	25.10.2020	77 092	10
CSSC TAI YUAN	20.02.2020	02.03.2020	76 309	11
FUHAI	10.01.2021	18.01.2021	88 048	8
WEI QIN	13.03.2021	26.03.2021	65 246	13
ALPS	19.06.2021	29.06.2021	64 382	10

HONG XIANG	27.07.2021	08.08.2021	64 283	12
Seiyo Harmony	06.04.2021	20.04.2021	26 307	14
AQUAKNIGHT	16.11.2021	28.11.2021	71 027	12
MIMITSU	19.04.2021	01.05.2021	29 739	12
YARRA STAR	19.08.2021	01.09.2021	75 492	13
Coral Ruby	18.06.2021	26.06.2021	70 874	8
GOLDEN PEARL	11.11.2021	22.11.2021	66 870	11
DL ADONIS	19.06.2021	01.07.2021	72 904	12
New Endeavor	14.10.2021	24.10.2021	72 482	10
STAR APHRODITE	19.01.2021	30.01.2021	75 961	11
TW HAMBURG	02.05.2021	11.05.2021	76 591	9

Appendix 3

Table 54. Coal vessels ship calls from Murmansk through Suez Canal to Guangzhou in 2015-2021. Source: AXS Dry database

Vessel	Departure Date	Arrival Date	Volume intake	Voyage days
Strelitzia	09.04.2016	01.06.2016	80 705	53
Sally	05.07.2016	01.09.2016	108 545	58
HK Delight	28.08.2016	20.10.2016	80 705	53
Tai Strength	07.09.2016	04.11.2016	75 100	58
Tai Stamina	06.10.2017	01.12.2017	73 670	56
Ruby	26.02.2017	21.04.2017	103 983	54
Pearl	11.06.2017	07.08.2017	79 815	57
Dragon Sky	10.01.2018	05.03.2018	64 229	54
Summer Sky	10.04.2018	01.06.2018	70 472	52
Lila	22.11.2018	13.01.2019	63 888	52
Golden Suek	06.03.2019	29.04.2019	52 764	54
Feng Mao Hai	15.02.2020	10.04.2020	71 526	55
Core Imperial	07.07.2020	27.08.2020	68 170	51
Pan Quest	15.08.2020	06.10.2020	70 810	52
Golden Suek	10.09.2020	05.11.2020	73 372	56
PAC Alcamar	30.03.2020	23.05.2020	89 301	54
PAC Alcor	11.02.2020	03.04.2020	100 565	52
Azalea Island	24.04.2020	20.06.2020	88 515	57
Golden Strength	07.05.2020	01.07.2020	100 993	55
GENEROSITY	15.08.2020	10.10.2020	80 996	56
Golden Strength	11.07.2021	01.09.2021	70 887	52
IOLI	17.03.2021	13.05.2021	79 617	57
NORD LIBRA	06.06.2020	01.08.2020	102 848	56
MARAN PROGRESS	09.05.2021	05.07.2021	72 771	57

Appendix 4

Table 55. Coal vessels ship calls from Taman to Guangzhou in 2015-2021. Source: AXS Dry database

Vessel	Departure Date	Arrival Date	Volume intake	Voyage days
Bulk Castor	03.06.2015	13.07.2015	80 445	40
Draftslayer	17.04.2015	26.05.2015	84 450	39
NC Crystal	06.04.2015	16.05.2015	78 910	40
Tomaros	03.02.2015	15.03.2015	63 950	40
Donald M. James	04.06.2015	15.07.2015	84 450	41
Ireland	25.03.2015	01.05.2015	86 848	37
Zhong Hui 68	07.08.2015	15.09.2015	66 102	39
Zhong Hao 88	02.01.2015	12.02.2015	81 390	41
Pan Regina	06.02.2016	17.03.2016	100 844	40
Ultra Dynamic	01.08.2017	10.09.2017	86 010	40
Yasa Venus	14.04.2017	25.05.2017	78 405	41
NORD SAVANNAH	11.03.2018	15.04.2018	90 072	35
PONTONIKIS	01.08.2018	10.09.2018	63 208	40
SAMC EDDIE	27.01.2021	08.03.2021	80 217	40
MARAN INNOVATION	03.03.2021	10.04.2021	79 692	38
BALTIMORE	19.03.2021	25.04.2021	81 365	37
Great Tang	25.03.2021	05.05.2021	82 829	41
KSL SANTOS	09.04.2021	21.05.2021	83 651	42
GOLDEN INCUS	06.06.2021	16.07.2021	84 495	40
EHIME QUEEN	18.06.2021	26.07.2021	67 814	38
FABULOUS	02.11.2021	13.12.2021	72 700	41
KAVO YERAKI	30.09.2021	08.11.2021	37 780	39

Appendix 5

Table 56. Bulker vessels ship calls from Murmansk through Northers Sea Route to Dezhnev Cape in 2015-2021 in summer. Source: AXS Dry, Clarksons

Vessel	Departure Date	Arrival Date	Voyage days
ТХ СЕВЕРНАЯ ЗЕМЛЯ	24.03.2015	09.04.2015	16
ТХ КАПИТАН СВИРИДОВ	30.03.2015	14.04.2015	15
ТХ ГРУМАНТ	03.04.2015	21.04.2015	18
ТХ МИХАИЛ КУТУЗОВ	15.04.2015	23.05.2015	38
ТХ АЛЕКСАНДР СУВОРОВ	25.05.2015	19.06.2015	25
KUMPULA	20.07.2015	05.08.2015	16
ПЕТР ВЕЛИКИЙ	23.09.2015	13.10.2015	20
ПЕТР ВЕЛИКИЙ	09.03.2016	30.03.2016	21
КУЗЬМА МИНИН	23.03.2016	10.04.2016	18
ЗАПОЛЯРЬЕ	15.04.2016	12.05.2016	27
GRETKE OLDENDORFF	01.08.2016	26.08.2016	25

КАПИТАН СВИРИДОВ	12.08.2016	22.08.2016	10
GEORG OLDENDORFF	29.08.2016	12.09.2016	14
NORDIC BOTHNIA	07.03.2017	01.04.2017	25
КУЗЬМА МИНИН	28.03.2017	19.04.2017	22
ПЕТР ВЕЛИКИЙ	17.04.2017	16.05.2017	29
АЛЕКСАНДР СУВОРОВ	19.05.2017	29.05.2017	10
ПЕТР ВЕЛИКИЙ	06.07.2017	18.07.2017	12
МИХАИЛ КУТУЗОВ	03.08.2017	11.08.2017	8
ГРУМАНТ	20.08.2019	06.09.2019	17
GEBE OLDENDORFF	20.09.2019	02.10.2019	12
GOLDEN SUEK	10.08.2020	25.08.2020	15
GEBE OLDENDORFF	19.08.2020	27.08.2020	8
GOLDEN STRENGTH	19.08.2020	28.08.2020	9
GEORG OLDENDORFF	01.09.2020	11.09.2020	10
KASPAR OLDENDORFF	15.09.2020	22.09.2020	7
GOLDEN PEARL	23.09.2020	01.10.2020	8
ADMIRAL SCHMIDT	16.07.2021	25.07.2021	9
GOLDEN FURIOUS	22.07.2021	03.08.2021	12
KUMPULA	26.07.2021	08.08.2021	13
GOLDEN SUEK	03.08.2021	13.08.2021	10
GOLDEN PEARL	05.08.2021	11.08.2021	6
MV GOLDEN ENTERPRISE	11.08.2021	23.08.2021	12
REGINA OLDENDORFF	30.08.2021	14.09.2021	15
GOLDEN PEARL	02.09.2021	08.09.2021	6
RIK OLDENDORFF	06.09.2021	12.10.2021	36
KUMPULA	09.09.2021	11.10.2021	32
RICHARD OLDENDORFF	09.09.2021	05.10.2021	26
CONRAD OLDENDORFF	15.09.2021	25.09.2021	10
GOLDEN FURIOUS	20.09.2021	29.09.2021	9
GERTRUDE OLDENDORFF	21.09.2021	29.09.2021	8
ROLAND OLDENDORFF	21.09.2021	05.10.2021	14

Appendix 6

Table 57. Bulker vessels ship calls from Murmansk through Northers Sea Route to Dezhnev Cape in 2015-2021 in winter Source: AXS Dry, Clarksons

Vessel	Departure Date	Arrival Date	Voyage days
ТХ ПАВЕЛ ВАВИЛОВ	26.02.2015	25.03.2015	27
КУЗЬМА МИНИН	09.12.2016	29.12.2016	20
КАПИТАН СВИРИДОВ	12.12.2016	27.12.2016	15
КУЗЬМА МИНИН	09.01.2017	30.01.2017	21

КАПИТАН СВИРИДОВ АЛЕКСАНДР	16.01.2017	29.01.2017	13
СУВОРОВ	19.01.2017	06.02.2017	18
NORDIC BOTHNIA	07.02.2017	26.02.2017	19
NORDIC BARENTS	28.02.2017	16.03.2017	16
ПЕТР ВЕЛИКИЙ	17.11.2017	12.12.2017	25
NORDIC OLYMPIC	22.10.2018	05.11.2018	14
NORDIC OSHIMA	29.10.2018	25.11.2018	27
NORDIC OSHIMA	21.10.2019	30.10.2019	9
VITUS BERING	11.11.2019	22.11.2019	11
GOLDEN STRENGTH	07.10.2020	17.10.2020	10
NORDIC ODIN	13.10.2020	25.10.2020	12
VITUS BERING	14.10.2020	25.10.2020	11
NORDIC OLYMPIC	22.10.2020	19.11.2020	28
GOLDEN STRENGTH	26.10.2020	05.11.2020	10
GOLDEN PEARL	28.10.2020	05.11.2020	8
GOLDEN SUEK	01.10.2021	21.11.2021	51
KUMPULA	04.10.2021	13.10.2021	9
GOLDEN PEARL	11.10.2021	29.10.2021	18
GOLDEN FURIOUS	15.10.2021	29.10.2021	14
NORDIC NULUUJAAK	25.10.2021	19.11.2021	25
ADMIRAL SCHMIDT	28.10.2021	08.11.2021	11
NORDIC QINNGUA	01.11.2021	21.11.2021	20
VITUS BERING	02.11.2021	26.11.2021	24
KUMPULA	08.11.2021	25.11.2021	17
GOLDEN PEARL	10.11.2021	30.11.2021	20

Appendix 7

Table 58. Seasonality check for freight rate from Vanino. Source: constructed by the author

```
g dm = time
format dm %10.0g
di (53 - 60)*12
list in 1/10
gen date = dofm(dm)
format date %d
list in 1/10
gen month=month(date)
gen yr=year(date)
*generate 1 for January, 2 for February...
generate m = month(dofm(time))
generate m1=(m==1)
generate m2=(m==2)
generate m3=(m==3)
generate m4=(m==4)
generate m5=(m==5)
generate m6=(m==6)
generate m7=(m==7)
generate m8=(m==8)
generate m9=(m==9)
generate m10=(m==10)
generate m11=(m==11)
```

```
generate m12=(m==12)
reg Vanino i.m
predict ehat, residual
g season = Vanino - ehat
twoway (tsline Vanino) (tsline season)
egen Vanino_m = mean(Vanino)
g Vanino_adj = ehat+ Vanino_m
twoway (tsline Vanino) (tsline Vanino_adj)
```

Appendix 8

```
. arima Vanino, arima(1,2,0) //for Vanino Transshipment

(setting optimization to BHHH)
Iteration 0:   log likelihood = -227.05088
Iteration 1:   log likelihood = -227.04817
Iteration 2:   log likelihood = -227.04755
Iteration 3:   log likelihood = -227.04735
Iteration 4:   log likelihood = -227.04726
(switching optimization to BFGS)
Iteration 5:   log likelihood = -227.04723
Iteration 6:   log likelihood = -227.04718
Iteration 7:   log likelihood = -227.04718

ARIMA regression

Sample:  2015m3 - 2022m12                   Number of obs     =         94
                                            Wald chi2(1)      =      30.74
Log likelihood = -227.0472                  Prob > chi2       =     0.0000
```

D2.Vanino	Coef.	OPG Std. Err.	z	P>|z|	[95% Conf.	Interval]
Vanino						
_cons	.0000109	.2300851	0.00	1.000	-.4509476	.4509693
ARMA						
ar L1.	-.3994673	.0720488	-5.54	0.000	-.5406803	-.2582543
/sigma	2.706201	.1199438	22.56	0.000	2.471116	2.941287

Akaike's information criterion and Bayesian information criterion

Model	Obs	ll(null)	ll(model)	df	AIC	BIC
.	94	.	-227.0472	3	460.0944	467.7242

Note: N=Obs used in calculating BIC; see [R] BIC note

Appendix 9

```
. arima Vanino, arima(1,1,0) //for Vanino Transshipment

(setting optimization to BHHH)
Iteration 0:   log likelihood = -210.74129
Iteration 1:   log likelihood =  -210.7394
Iteration 2:   log likelihood = -210.73899
Iteration 3:   log likelihood = -210.73881
Iteration 4:   log likelihood =  -210.7387
(switching optimization to BFGS)
Iteration 5:   log likelihood = -210.73864
Iteration 6:   log likelihood = -210.73854
Iteration 7:   log likelihood = -210.73854

ARIMA regression

Sample:  2015m2 - 2022m12                       Number of obs     =         95
                                                Wald chi2(1)      =       2.81
Log likelihood = -210.7385                      Prob > chi2       =     0.0938
```

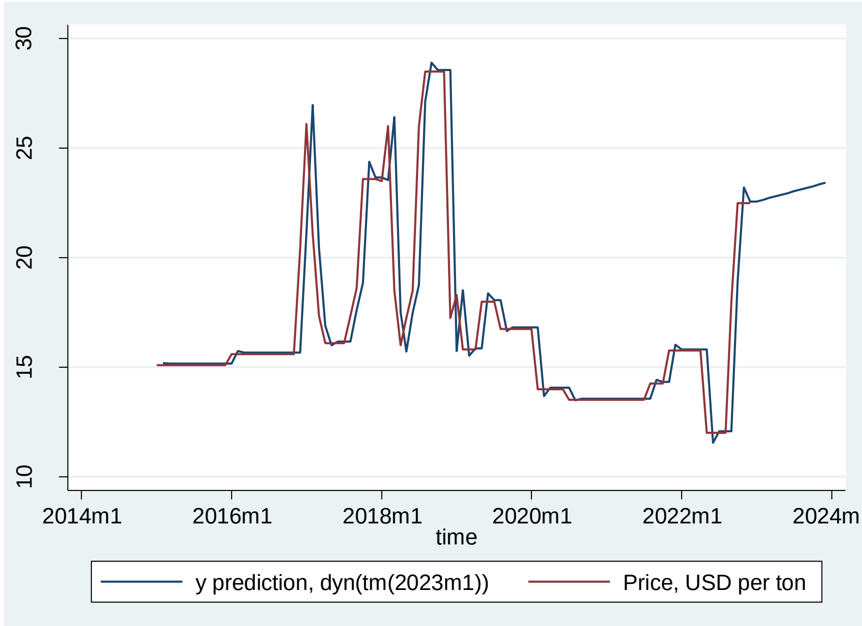
D.Vanino	Coef.	OPG Std. Err.	z	P>|z|	[95% Conf.	Interval]
Vanino						
_cons	.0776623	.3044728	0.26	0.799	-.5190934	.674418
ARMA						
ar L1.	.1411826	.0842425	1.68	0.094	-.0239296	.3062948
/sigma	2.223901	.0739414	30.08	0.000	2.078979	2.368823

```
. estat ic //for Vanino Transshipment
```

Akaike's information criterion and Bayesian information criterion

Model	Obs	ll(null)	ll(model)	df	AIC	BIC
.	95	.	-210.7385	3	427.4771	435.1387

Appendix 10



Appendix 11

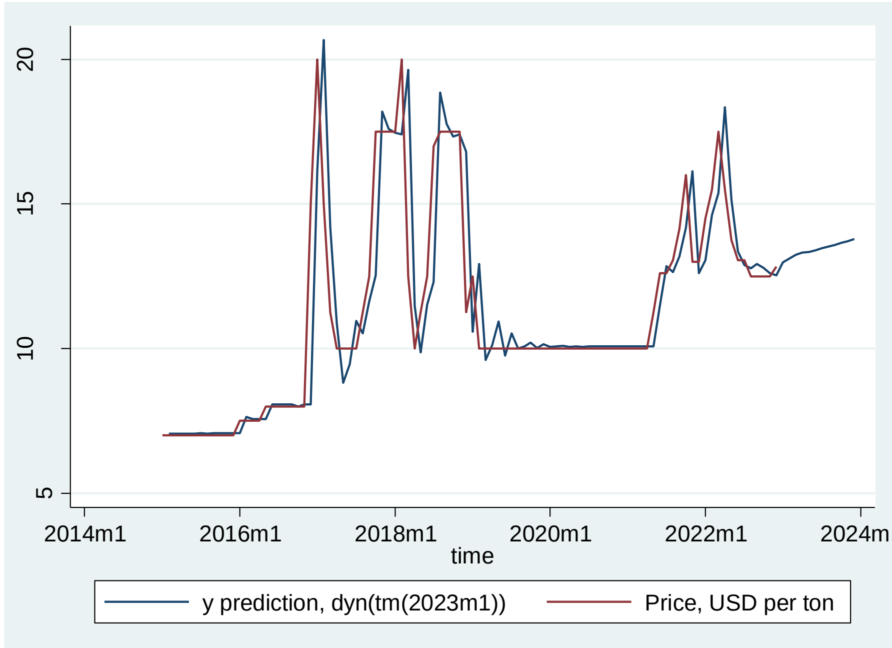
```
ARIMA regression

Sample:  2015m2 - 2022m12                       Number of obs     =         95
                                                Wald chi2(2)      =       7.81
Log likelihood =  -189.594                      Prob > chi2       =     0.0201
```

D.Murmansk	Coef.	OPG Std. Err.	z	P>|z|	[95% Conf. Interval]	
Murmansk						
_cons	.0637894	.231699	0.28	0.783	-.3903323	.5179111
ARMA						
ma L1.	.1508289	.0774372	1.95	0.051	-.0009452	.3026031
ARMA5						
ma L1.	-.160274	.0808939	-1.98	0.048	-.3188232	-.0017248
/sigma	1.778915	.0751692	23.67	0.000	1.631587	1.926244

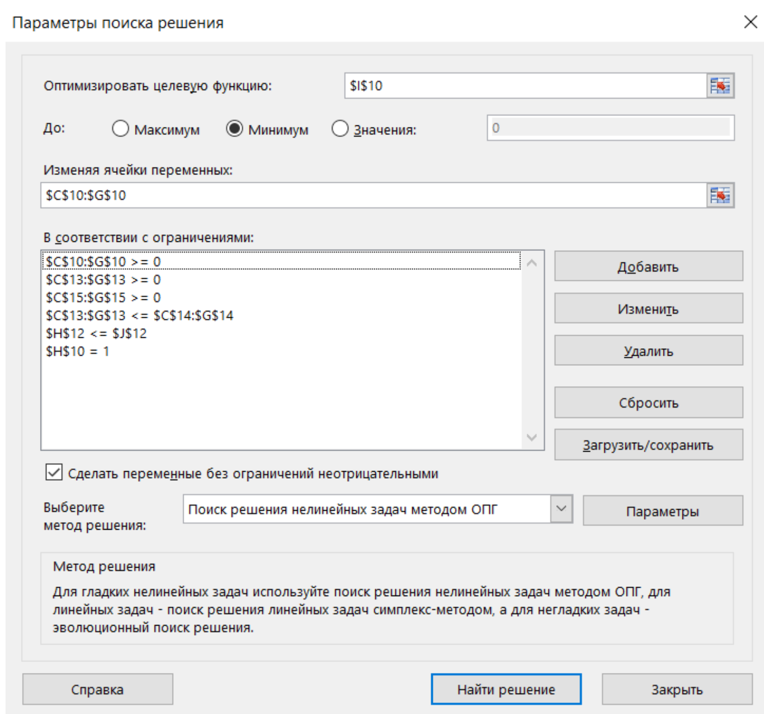
Akaike's information criterion and Bayesian information criterion

Model	Obs	ll(null)	ll(model)	df	AIC	BIC
.	95	.	-189.594	4	387.188	397.4035

Appendix 12


20
15
10
5
2014m1
2016m1
2018m1
2020m1
2022m1
2024m1
time
y prediction, dyn(tm(2023m1))
Price, USD per ton

Appendix 13


Параметры поиска решения
Оптимизировать целевую функцию:
$I$10
До:
Максимум
Минимум
Значения:
0
Изменяя ячейки переменных:
$C$10:$G$10
В соответствии с ограничениями:
$C$10:$G$10 >= 0
$C$13:$G$13 >= 0
$C$15:$G$15 >= 0
$C$13:$G$13 <= $C$14:$G$14
$H$12 <= $J$12
$H$10 = 1
Добавить
Изменить
Удалить
Сбросить
Загрузить/сохранить
Сделать переменные без ограничений неотрицательными
Выберите метод решения:
Поиск решения нелинейных задач методом ОПГ
Параметры
Метод решения
Для гладких нелинейных задач используйте поиск решения нелинейных задач методом ОПГ, для линейных задач - поиск решения линейных задач симплекс-методом, а для негладких задач - эволюционный поиск решения.
Справка
Найти решение
Закрыть