ARBITRAGE OPPORTUNITIES
ON EASTERN EUROPEAN
NATURAL GAS MARKET

by

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bcm billion cubic meters

CEGH Central European Gas Hub

GTS Gas Transmission System

IEA International Energy Agency

LNG Liquified Natural Gas

NFC Non-Financial Corporations

TSO Transmission System Operator

TTF Title Transfer Facility

UGS Underground Gas Storage

CHAPTER 1. INTRODUCTION

In November 2015 Ukraine ceased import of natural gas from Russian companies. Besides political reasons, such a response was a result of increasing tensions with Gazprom on two key questions: terms of Russian gas transit to Europe through Ukrainian GTS, and price of gas import to Ukraine. According to Minister of Energy of Ukraine Volodymyr Demchyshyn, gas price proposed by Gazprom in 2015 (247,8 USD/tcm) was even higher than price for reverse import of gas from European countries.

This decision was a part of complex Ukrainian gas market reform launched in 2014. The following steps – adoption of new legislation, unbundling of gas transmission from supply and production, corporate governance reform of Naftogaz of Ukraine (the largest energy company in Ukraine, state-owned), partial liberalization of domestic natural gas prices etc. – resulted in dramatic changes of gas market landscape.

As of October 2021, Ukraine has not been purchasing gas from Russian companies for more than 2100 days, covering all gas demand by domestic gas production and imports from European countries (Poland, Slovakia, Hungary). According to Reuters, Poland also aims at decreasing its dependence on Russian gas and does not plan to sign new long-term contract with Gazprom in 2022. As an alternative, Poland and Ukraine aims at diversification of gas supplies: Ukraine works on expanding its cross-border interconnection capacity with neighboring countries and developing Trans Balkan gas corridor (to enhance gas flows in south-north direction); Poland has already built LNG terminal on Baltic Sea and plans to build gas pipeline to import gas from the North Sea.

While the key focus of Eastern European countries is diversification of gas supplies, Europe's role on the World's gas market is also subject to dramatic changes in the nearest future. According to International Energy Agency, "Following a record of 115 bcm of LNG imports in 2019, we [IEA] expect Europe to continue to play a key role in balancing the global gas market – providing access to its spare regasification capacity, ample storage space and liquid pricing hubs". Each year European gas market becomes even more integrated as a result of law unification, increasing interconnection capacities and enhancing transparency of the gas market participants. With a more transparent market structure, the number of traders on the gas market increases, while more integrated market provides them with variety of trading opportunities. However, alongside with large and liquid gas exchanges, there are local markets at which liquidity is not as large, so market inefficiencies still could arise.

In this context, a closer integration of Ukraine's natural gas market into the European system could have significant effect on demand-supply balance on the European (and Global) gas markets, primarily due to large underground gas storage (UGS) facilities available in Ukraine. Consequently, deregulation, liberalization and closer integration of the Ukrainian gas transmission and storage system into the European one that has being happening since 2014, provide European gas traders with more transparent and easy access to a new instrument – storage of natural gas in Ukrainian UGS, with further sale of gas to either Ukrainian market or reexporting it back to EU countries. In fact, it adds one more option for traders willing to exploit difference between forward and spot markets.

This topic becomes the one of particular interest primarily due to (i) introduction of completely new gas-related services in Ukraine during last years, that significantly affected regional gas market ("short haul" and "customs warehouse"), (ii) lack of data-based research of spot-forward arbitrage on Eastern-European gas market, and (iii) significant decrease of European spot gas prices in 2020 as a result of an oversupplied market due to imposed quarantine measures and suspended economic activity.

Thus, the key point of interest of this research is whether spreads between European forward and spot gas markets are large enough to enable gas traders to profit from them using Ukrainian gas storage.

Methodologically, this research is based on comparison of prices on deliverable spot and forward markets, with accounting for transaction costs (transportation, storage, interest). The analysis was concentrated on the dataset of prices from the beginning of 2020 till August 2021. The time period was chosen because of introduction of the short-haul regime by Ukrainian TSO from January 1st, 2020. This regime, combined with customs warehouse service, allowed traders to import gas to Ukraine at about four times lower price than before, store it in Ukrainian UGS for the period of up to 1095 days, and then re-export it to the EU (also at lower price than before).

Analysis of two routes – Hungary -> Ukraine -> Slovak Republic -> Austria and Austria -> Slovak Republic -> Ukraine -> Slovak Republic -> Austria – showed that arbitrage opportunities were available during Summer of 2020, when the gas storages was at higher-than-usual levels due to weak industrial demand (due to COVID-19) and relatively warm winter. Further investgation showed that the arbitrage was fully exploited by market participants during June-August. Based on this information we concluded that the gas market was efficient, but its institutional imperfections combined with capacity restricitons and extraordinary situation caused by restrictions related to COVID-19 resulted in the fact that it took more than four months to fully utilize arbitrage opportunities available at the market.

Our econometric modelling showed that dynamics of the spread between Forward and Day-Ahead prices at CEGH exchange (Austria) could be described reasonably well with 3 factors – lagged change of the spread during previous 5 trading days, deviation in fullness of gas storage in Europe from historical average, and weekday. The estimated coefficients provided supportive evidence to the hypothesis of the efficient market, because spread between forward and spot market tend to reverse to the mean value after shocks (90% of a shock goes off within 13 trading days after shock appeared).

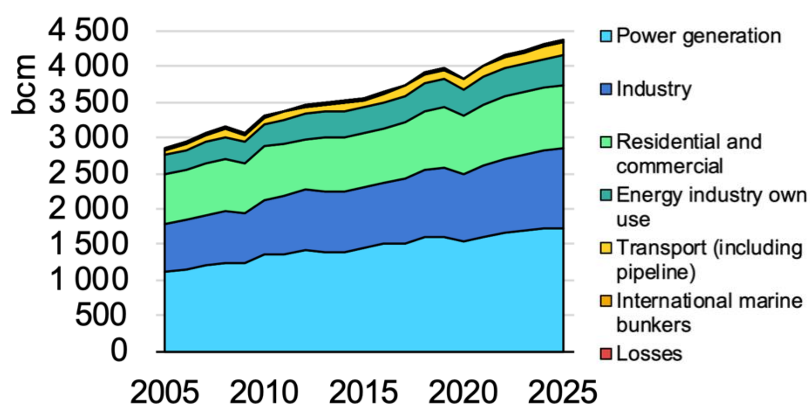
CHAPTER 2. INDUSTRY OVERVIEW AND RELATED STUDIES

2.1. Industry overview

Global natural gas industry could be divided to 3 key subindustries – upstream, midstream, and downstream. Upstream industry consists of companies engaged in development, exploration, and production of natural gas; midstream companies are working on processing, transportation and storing of natural gas, either in gaseous or liquid form. Consequently, primarily focus of downstream companies is distribution and supply of natural gas to residential and business customers.

Industrial production and use of natural gas have started in 19th century and was primarily used for cooking and as a source of light. Later, with development of technology and infrastructure, humanity has found various implications for natural gas. In the 21st century, the demand for natural gas comes from 3 key industries – power generation, industrial production (primarily, chemicals) and residential consumption.

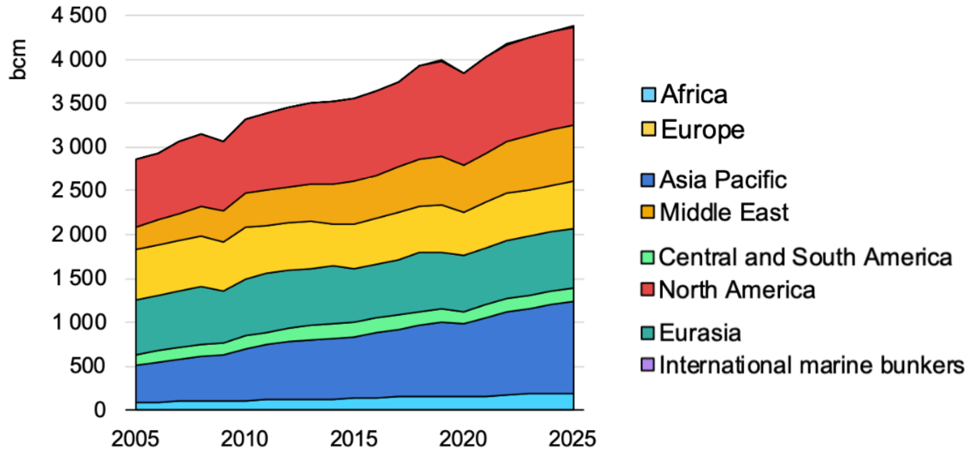
Figure 1. Global natural gas demand by sector, 2005-2025



Source: International Energy Agency, Gas 2020 report

Key global players on the demand side are North America and Asia-Pacific regions (primarily, China and Japan). Other regions (Europe, Middle East, and Eurasia) account for 50% of global demand in 2020 and also play an important role on the market (see Figure 2).

Figure 2. Global natural gas demand by region, 2005-2025



Source: International Energy Agency, Gas 2020 report

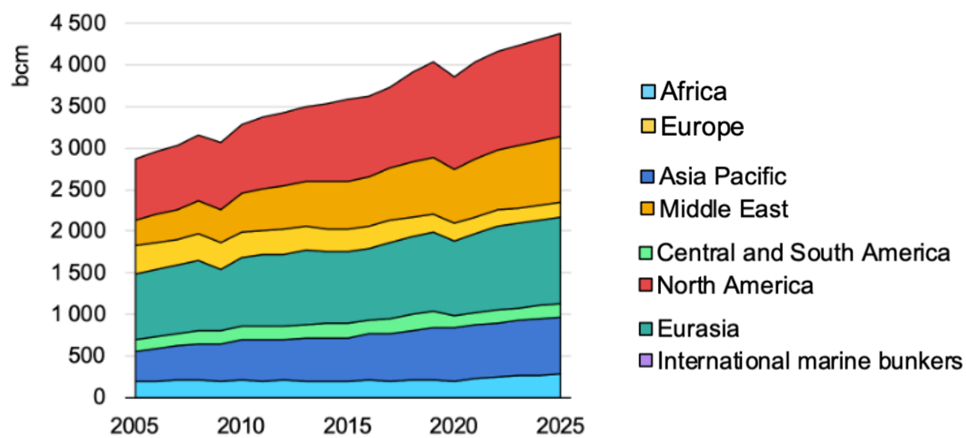
According to IEA, in 2020-25 the major part of Global gas industry growth will be driven by fast-growing Asia-Pacific region (primarily, China and India) and Middle East (Iran and Saudi Arabia).

Gas supply is not as diversified as demand – the key suppliers are North America, Middle East, and Eurasia (primarily, Russia). The breakdown by regions is illustrated on Figure 3. Experts of IEA expect that natural gas supply from European countries will continue its gradual decrease trend, driven by depletion of natural gas stock in the North Sea.

From the above, European gas market could be characterized as the market with quite high level of demand, driven by developed chemicals industry. Furthermore, the demand is expected to increase slightly during following years as a consequence of decarbonization trend which results in gradual phase-out of nuclear and coal-fired power plants, which should be substituted by gas-fired power plants in the nearest future to ensure stability and ability of energy system to balance renewables generation. But from the perspective till 2050, gas demand in power and industrial sectors is planned to be gradually substituted by 'green' products – renewables generation, green hydrogen and its derivative products, etc.

But it is important to take into account that this transition is limited by various factors, primarily technological (costs of electricity storage systems, cost of transportation of hydrogen), so the long-term prospects of gas demand are subject to ambiguous assumptions.

Figure 3. Global natural gas supply by region, 2005-2025



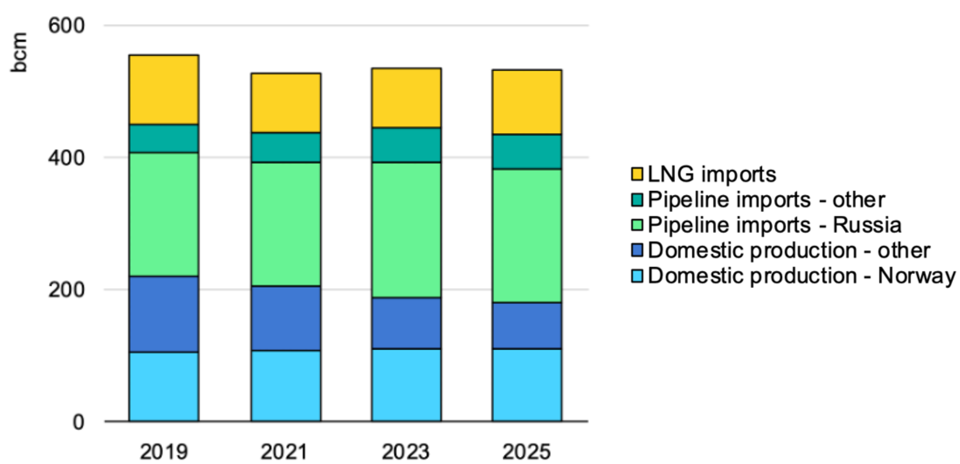
Source: International Energy Agency, Gas 2020 report

On the other side, own production of natural gas in Europe is lower than demand, and as far as supply is expected to fell further due to decrease in production in Norway (Troll and Oseberg) and Netherlands (Groningen field), further increase in imports is expected. Historical and expected structure of supplies on European gas market is described on the Figure 4.

IEA data shows that in 2019 40% of European demand were covered by domestic gas production, and 33% of demand (more than half of the import) was covered by gas with Russian origin. According to the forecasted structure of supply, by 2025 share of own gas supply will decrease to 33%, and share of Russian supplies will increase to 38%.

This fact is a key to understanding European gas market. Diversification of supply structure in order to decrease dependence on Russian gas is one of the key topics in energy policy discussions in Europe, and development of LNG terminals in order to increase imports from the US and other countries is part of this policy. This discussion became much more active during autumn 2021, when sudden shortages occurred due to fast gas demand recovery and unexpectedly low storage levels driven by limited gas supply from Russia. Some analysts argue that Gazprom's decision to keep their supply limited despite record-high prices in Europe is driven by willingness to force European regulatory bodies to make an exception for the Nord Stream-2 (NS-2) from the Third Energy Package, or at least authorize NS-2 to start operations as soon as possible.

Figure 4. Evolution of European natural gas supply, 2019-25

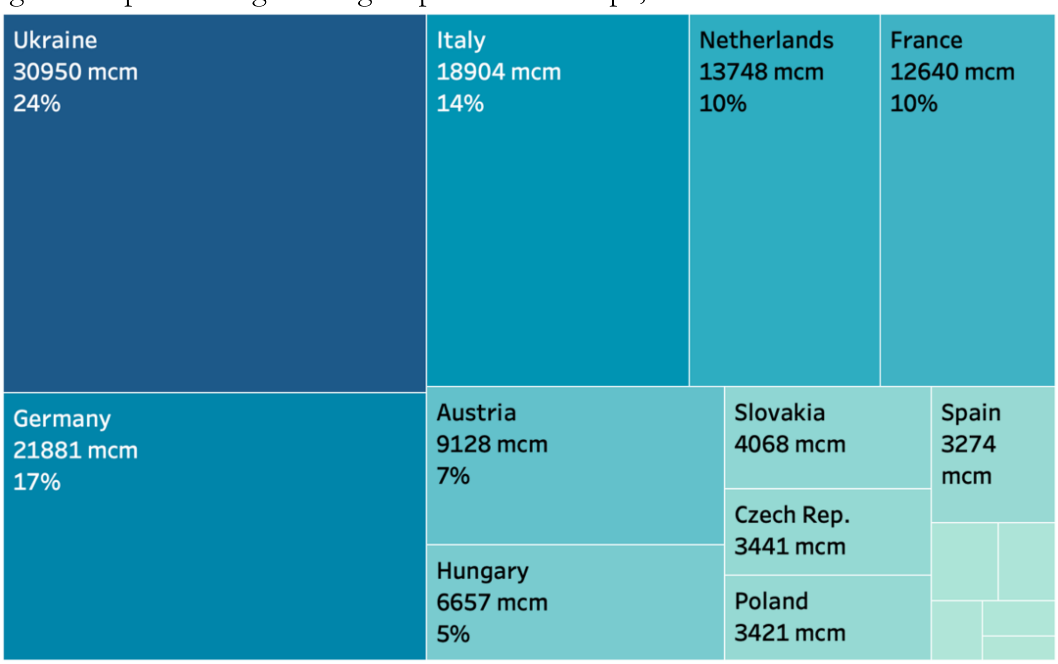


Source: International Energy Agency, Gas 2020 report

Eastern European market has similar characteristics – insufficient domestic supply and high dependency on Russian gas imports. Launch of NS-2 mentioned above could have severe consequences for this region, because decrease in it could result in decrease of transit of Russian gas from 2024 and could negatively affect energy security of countries in the region. According to Oxford Institute for Energy Studies, after expiration of current Gazprom-Naftogaz contract in 2024, Ukrainian transmission system will be used only for residual Gazprom flows of 10-20 bcm per year (minimal booked capacity according to the contract is 65 bcm in 2020 and 40 bcm in 2021-24).

Key distinctive feature that makes this regional segment of European gas market unique is large amount of gas storage capacities, which enable market players effectively manage issues with intertemporal inconsistencies between demand and supply and exploit arbitrage opportunities if changes in market prices on different markets result in presence of market inefficiencies. Furthermore, in the context of discussed above, these gas storage facilities are also important to maintain Europe's key role in balancing global gas market and provide security for the region from supply fluctuations. In this aspect, Ukraine has unique position, because Ukrainian gas storage system has the largest capacity among all European countries – it accounts for almost 31 billion cubic meters of storage, ~22% of overall European gas storage capacity.

Figure 5. Operational gas storage capacities in Europe, million m^3



Source: Naftogaz of Ukraine

In 2014 Ukraine started complex reform of its gas market, aiming at achieveing better energy security. This process involved switch from import gas from Russia to European suppliers, adoption of european legislation and regulations, unbundling of gas transmission system from supply and production, corporate governance reform of Naftogaz of Ukraine (the largest energy company in Ukraine, state-owned), partial liberalization of domestic natural gas prices etc.

S&P analysts in November 2020 highlighted that "Although Eastern and Southern European countries remain heavily reliant on Russian long-term contracted gas, the development of new gas hubs in this region triggered by Ukraine is slowly contributing to the diversification of regional sources of supply". Thus, changes in Ukraine aimed at diversification of own supply sources also affected neighboring markets and resulted in changes of gas market landscape in the region.

As a part of gas market reform that, Ukrainian TSO introduced 2 important services, that significantly affected the landscape of the market and contributed to the closer integration of Ukraine with European gas market. 'Customs warehouse' service was launched in 2017 and enabled traders to import gas to Ukraine for up to 1000 days without paying import duties and VAT in Ukraine, with an opportunity to reexport it back to EU (without paying duties and VAT at all) or sell to Ukrainian domestic market (and pay duties and VAT only at the moment of sale). It decreased working capital requirements for operations with the Ukrainian market and decreased amount of bureaucratic work needed for traders. 'Short haul' is a discounted transportation service which was introduced in 2020 and enabled traders to transport gas between dedicated interconnection points with neighboring countries at lower price than before. According to Ukrainian TSO, the average cost of the route between neighboring European countries through Ukraine became 4 times cheaper with this service. Moreover, short-haul service could be combined with customs warehouse, which makes Ukrainian storage more attractive for European traders than before and adds liquidity to this regional market.

In this context it is important to mention that the natural gas market is characterized by different seasonality of gas demand and supply: gas demand is uneven during a year due to high demand during winter (primarily by residential sector and utilities), while gas production is relatively stable during a year. In practice it resulted in introduction of industry-specific terms – Gas Summer and Gas Winter (hereinafter referred as Summer and Winter respectively). During Summer (April-September) market players put excess gas into the gas storages, and during Winter (October-March) withdraw this gas to cover extra supply. This situation results in the seasonality of prices. Typically, gas price is lower during Summer, so traders could benefit from buying gas during Summer, and storing it in gas storages and selling during Winter.

Furthermore, as mentioned above, gas demand and gas production are frequently located in different areas, so gas prices in deficit regions (demand > production) are typically higher than in the regions with gas surplus (production > demand). For example, in the S&P article mentioned above, authors pointed out that "During the summer of 2020, Italian traders active on the Italian PSV and at the Austrian CEGH lost one of their traditional plays, exploiting arbitrage opportunities offered by the typical premium of the Italian PSV contracts to the CEGH equivalent".

Thus, in the context of closer integration of Ukrainian gas transmission system to the European one, and better access of gas market participants to Ukrainian gas storages, this research is concentrated on the ability of Ukrainian gas storage to provide traders with an opportunity to benefit from seasonal differences in prices (i.e., provide them with arbitrage opportunities).

2.2. Related studies

Recent studies that focus on arbitrage opportunities on the gas market have primarily focus on arbitrage across all Europe (between the largest gas hubs), across different regions (e.g., between North America and Europe) and between different products (e.g., LNG and natural gas in form of gas).

Brown and Yücel (2009) employed bivariate causality tests between gas prices in the United States (Henry Hub) and United Kingdom (NBP hub), and the role of oil prices (WTI, Brent) in the pricing of natural gas across Atlantics. Their analysis shows that there are coordinated movements in natural gas prices between these regions, which suggests the possibility of arbitrage that could be exploited through LNG shipments. But at the same time, they pointed out that the arbitrage was restricted by the capacities of LNG infrastructure. This research was based on weekly natural gas and oil prices, and to make conclusions about the relationship between gas prices they employed a bivariate error-correction model with 4 lags of both components.

In a more recent study, Nick (2016) focused on the informational efficiency of European gas hubs. His findings support the hypothesis that futures market participants react more efficiently compared to the spot market players due to better informational efficiency at this market. Also, he indicated that the theory of storage holds at all considered gas hubs in the long run, so the intertemporal arbitrage in the long run had low efficiency. On contrary, in the short run gas hubs were revealed to be not fully informational efficient. Regarding the reasons for availability of intertemporal arbitrage opportunities, he pointed out that it could be partially attributed both to low liquidity issues (higher liquidity contributes to higher informational efficiency at some hubs) and physical characteristics of a market (limited infrastructure flexibility, inefficient allocation of storage capacity etc.). The research is based on daily spot and month-ahead futures (one, two and three months) prices at 6 key European gas hubs (NCG, GP, TTF, NBP, PEGN, CEGH) for the period from October 2007 till August 2012.

Another paper by Dehnavi, Wirl and Yegorov (2015) indicated the existence of inter-regional arbitrage, especially between the low-price US and high-price European and Japanese markets. However, they pointed out an important restriction: this type of arbitrage requires additional attention to the capacity of infrastructure, regulatory constraints and significant investment requirements to exploit arbitrage opportunities on markets that are connected only via marine transport.

Further analysis showed that the question of arbitrage with different types of assets is widely covered in the scientific works, e.g. by Brennan and Schwartz (1990), Doukas, Chansog and Pantzalis (2010), Duarte, Longstaff and Yu (2007), Gromb and Vayanos (2010), Shleifer and Vischny (1997), Weber (1979), Werner (1987). But these works are primarily concentrated on other underlying (stocks, interest rates, bonds), while the question of intertemporal arbitrage is not as widely covered in the literature. Furthermore, no academic papers related to the intertemporal arbitrage in the Eastern European natural gas market using Ukrainian gas storage was found, so the research topic is relevant.

CHAPTER 3. METHODOLOGY

There are two steps in the research: analyzing whether arbitrage opportunities between certain markets actually existed, and determining which factors are driving the availability of the arbitrage.

To proceed with a first step, the arbitrage should be defined. As mentioned in Chapter 2, different types of arbitrage could be defined – between different regions, time periods, products etc. Hereinafter, by arbitrage opportunity we mean positive difference between future price of the natural gas and its current (spot) price, large enough to cover all transaction costs associated with the respective risk-free trading operation. By the risk-free operation we meant that the purchase and sale are conducted at the same moment, and transaction costs are determined by TSO operators in advance, so the profit is pre-determined and is subject only to counterparties credit risk, which is mitigated if the transaction takes place on the exchange. In addition, arbitrage profit (loss) could be defined as the forward price of an asset minus spot price minus transaction costs.

In the long term, the difference between forward and spot price should not allow for arbitrage, because if such opportunity exist, market players will purchase more gas today and offer more gas in the forwards market. This, in turn, will lead to increase in price of the asset today (due to higher demand) and decrease of price in the future (due to higher supply), so the difference become narrower, until the difference in prices becomes smaller or equal to the transaction cost.

Caumon and Bower (2004) state that the theory of storage (also known as cost-of-carry pricing) is a commonly used tool to analyze the relation between spot and futures/forward price. Here is how they explain the fundamentals behind this theory: "…in the presence of surplus stocks, the level of contango [positive difference between forward price and current price of an asset] cannot exceed the cost of carry otherwise risk free 'cash and carry' arbitrage trading operations would reestablish the equilibrium…". Thus, according to the theory of storage, the forward price F_t^{t+n} is a function of a spot price S_t, cost of storage c and interest rate i:

$$F_t^{t+n} = G(S_t, c, i) \quad (1)$$

In the short term, market inefficiencies (significant deviations from the equation 1) driven by various factors could occur. These factors could include deviations of an actual situation from the expected one, significant change in market expectations driven by players' decisions or exogeneous events etc. For example, if one of gas producers announce that it will halt gas production on the large gas field in 2 months for maintenance, this will be reflected in Month+2 forward price at this market through higher prices of gas suppliers. In turn, it could affect spot price, because market players may want to purchase gas from other countries today, sell it via M+2 forward and keep it in the storage till maturity. If it is an economically attractive trade, profit-seeking market players will arrange its execution, which on the one hand will result in higher gas demand today and will contribute to increase of the spot gas price, and on the other hand – increase supply in the forwards market, which will result in lower futures prices (ceteris paribus).

Execution of this trade could take some time (to get approval from the management, find financing, sign the contracts, etc.). Moreover, gas infrastructure capacity (gas pipeline, interconnectors between countries or regions, gas storages) is limited and could have not enough unused capacity. Thus, in some cases the execution of the trading scheme could require significant amount of time, during which arbitrage opportunity could not be efficiently exploited (in the short term). But in the long term, we can expect the arbitrage to be exploited, as market participants would have enough time to deal with all mentioned above market frictions and make respective transactions to profit from the spread (as described above). Or, if doing this with existing capacities is not not technically possible – remove capacity restriction (e.g., build new LNG terminal or gas storage).

However, there is an exception that should be considered. It is related to the nature of the gas market – gas transmission systems are usually owned and operated by natural monopolies (usually, government-owned companies). As a result, significant changes in gas infrastructure requires various approvals from different government bodies as well as large amount of CAPEX, so even in the long term such restrictions could exist.

In real market, deviations from relation (1) are possible not only as a result of market inefficiencies, but also as a result of seasonality of natural gas prices. With higher prices during Winter due to higher demand, we should not expect the scheme 'buy now, store and then sell in few months' to be economically rational. This state of the market is called "backwardation", and to address this issue equation (1) could be adjusted, so the equilibrium forward price is not higher than the forward price obtained using the "cash and carry" operation described above:

$$F_t^{t+n} \leq G(S_t, c, i) \tag{2}$$

As an alternative, to address this issue the concept of convenience yield was introduced by Kaldor (1939) and was applied for different commodities markets by Working (1949), Brennan (1958), Tesler (1958) and other economists. Caumon and Bower (2004) refer to the following calculation of a convenience yield as to a classical one:

$$CY = S(t) - F(t,T)\exp\left[-(r+c)*(T-t)\right], \tag{3}$$

where T and t determine the time horizon, c and r are storage cost and interest cost determined as ratio to the price of an underlying.

Actually, convenience yield is defined in such a way, so it accounts for all the differences between actual spot price and present value of the actual forward price. In terms of the arbitrage profit (loss) as defined above, convenience yield is the negative of the arbitrage profit (loss). Thus, in further research there is no need to include convenience yield to the calculation because both variables (arbitrage profit (loss) and convenience yield) has the same nature and could not be defined simultaneously.

Summarizing the theory above, the further research will be based on the following formula of the arbitrage profit (AP), that implies the theory of storage approach to the forward price definition and annual compounding of the interest:

$$AP = F_t^{t+n} - (S_t * (1+i)^n + c_{storage} + c_{transp} + c_{int}) \tag{4}$$

where

- F_t^{t+n} is a forward price in the period t for a gas delivered at period t+n;
- S_t is a spot price in the period t;
- i is an interest rate accrued on the cash amount required to finance the initial purchase of an asset;
- $c_{storage}$ is a storage cost associated with storing an asset for n periods;
- c_{transp} is a transportation cost associated with moving gas from point of purchase to the storage and from storage to the point of sale of an asset;
- c_{int} is an interest rate accrued on the cash amount needed to finance transaction expenses paid prior to the period t+n (when money for the gas sold are received).

In terms of equation (4), arbitrage opportunity exists if the LHS of the equation is positive. Consequently, the first step of the analysis (determine whether arbitrage opportunities between certain markets actually existed) requires few inputs: gas prices from real trades, costs associated with transportation and storage of gas, and minimum income required to make this transaction economically viable.

Further analysis is built based on spot and forward prices of the largest (from the point of view of volumes) gas hub in the Eastern Europe – CEGH, which is geographically located in Austria. Gas-related analytical agencies publish their estimations of the reference price achieved in deals at such gas hubs based on information from market participants. Usually, the information is published on the daily basis. Also, the analysis of arbitrage in related studies is based on either weekly, daily of intra-day data, depending on the data availability or purposes of the research. The highest frequency of the pricing data that is available for CEGH is daily data, so to be able to capture potential short-term market inefficiencies, the most frequent – daily data – was used.

Moreover, referring to Nick (2016) who pointed out that difference in liquidity between markets could result in availability of arbitrage opportunities, the further research includes analysis of 2 routes: Austria -> Ukraine -> Austria (actually, arbitrage between spot and forward markets of CEGH) and Hungary -> Ukraine -> Austria. The second route was chosen because the gas hub in Hungary – CEEGEX – is the fast-developing one that publishes reference prices online, but it has much lower liquidity comparing to the CEGH. In both cases, calculation implies that the spot price is paid the same day as the deal is made, because it is the most common way of settling the payment for such a deal.

Gas prices published at CEGH and other European gas exchanges are published at euros per megawatt-hour (EUR/MWh), so to ensure consistency, all calculations were made using MWh as a measure of gas quantity. In Europe it is widely used to address the issue related to the different qualitative characteristics of gas – so instead of pricing gas in per-volume units (e.g., per thousand of cubic meters), market participants price gas based on the amount of heat (and, as a result, of electricity) that could be produces using this gas. For conversion of indicators expressed in cubic meters, the following ratio was used: 1 000 cubic meters = 10.565 MWh.

The second component required for the calculation are transaction costs. Given the purpose of the research requires use of Ukrainian gas storage to keep gas between today and some moment in the future, the transaction costs will include: cost of transporting gas from the point of purchase to Ukraine, cost of storage in Ukrainian gas storage, and cost of transporting gas from Ukraine to the point of sale. Applied to the route Austria -> Ukraine -> Austria, it includes: exit fee from Austria and entry fee to Slovak Republic at Baumgarten point, exit fee from Slovak Republic and entry fee to Ukraine at Budince point, cost of injection to Ukrainian gas storage, cost of storing gas, cost of withdrawal of the gas from gas storage, exit fee from Ukraine and entry fee to Slovak Republic at Budince point, exit fee from Slovak Republic and entry fee to Austria at Baumgarten point. Regarding the route that starts at Hungary, the transaction cost includes exit fee from Hungary and entry fee to Ukraine at Bereg point, and the costs listed in the previous point after cost of injection to the gas storage (inclusive). The information listed above is published on the official websites of gas TSO and storage operators, usually in the format of calculators. The important characteristics of these tariffs is that they are relatively stable over time and usually are determined for the long period of time to make operations more forecastable for traders. In the calculation it is assumed that the transportation cost is paid at the moment of transporting of a gas, and cost of storage is accrued continuously throughout the period when the gas is stored in the UGS. For gas transported and stored during some period (e.g., month), it is assumed that the payment for transportation cost is made at the middle of the period.

The last component – the interest rate – is usually determined as a target hurdle rate on individual basis for each trading company. If income from the operation allows trader to earn yield higher than the hurdle rate, in this transaction the trader receives an economic profit, so it has an incentive to conduct such a trade. The hurdle rate is set based on various inputs, but 2 key inputs are cost of financing and structure of financing. Traders could use mix of equity and debt financing, or solely debt or equity financing. Taking into account the research question and the fact that usually in academic research calculation of arbitrage profit assumes 100% debt financing, further research is based on the assumption that the deal is 100% financed by debt. To make the analysis more applied, as a reference interest rate it is suggested to use average interest rate on revolving loans and overdrafts issued by European banks to non-financial corporations, published by the European

Central Bank. This rate implies that the trader has an agreement with the bank that allows to borrow money relatively fast if the business opportunity arises.

The second step of the analysis, determining which factors are driving the availability of the arbitrage, requires analysis of each component of the Equation 4. Prices of the forward and spot markets are driven by the expectation of market players regarding 6 key components in the period of delivery: (1) demand for gas (both for current consumption or for storing further), (2) price that consumers are ready to pay for the gas, (3) amount of gas production in the region, (4) availability of gas supplied via LNG or pipelines from other countries, (5) amount of gas in the local storages, (6) the price at which suppliers are ready to sell the gas they own. Data about market players' estimations of (1)-(2) and (6) is usually not public and hard to estimate. There are some analytical agencies that make such an analysis, but they publish it quite rare (quarterly or annually), with either factual data analysis or high-level forecasts, so it is hard to incorporate these factors to the analysis. Gas production (3) is relatively stable over time and usually all significant changes in the gas production are incorporated in prices in advance. Component (4) is usually relatively stable because it is determined based on long-term contracts between counterparties. The last component – level of gas in storages (5) is the one that is easily accessible for all market players (data on the level of gas storage is published online on a daily basis) and incorporates impact of all other factors, because unexpectedly occurred uncovered demand (either due to increase of demand or decrease of supply) is covered with withdrawal of gas from the storage, as well as excessive gas stock that originated from higher supply or lower demand immediately affects level of gas in the storage. Unfortunately, the data on expected gas stock in the future is not public, and different traders forecast it based on in-house fundamental models, so it is possible to incorporate to the analysis only the current level of the gas stock.

From the point of view of functional dependence, current level of gas storages affect both spot and forward prices, but taking into account nature of the term market we can expect that ceteris paribus impact of this factor on the spot price will be quicker and will have higher magnitude because of lower flexibility of gas supply in the short term, while in the longer time periods, it is possible to find other sources of additional supply or demand for gas (depending on the spot market situation). It is important to notice, that in analysis that is published by market participants it is common to express the current level of gas storage as the deviation of current stock from 5-year average, to reflect relative over- or under- supply comparing to the "normal" market circumstances.

As mentioned before, level of transaction costs are relatively stable over time and changes in it are announced well before the change, so incorporation of this factor to the analysis should not add significant value to the analysis.

Consequently, the second step of the research will be based on estimation of the regression model, where the dependent variable will be difference between forward and spot price, and independent variable is the level of gas in stock comparing to the 5-year average. Also, seasonal component (dummy variables for weekdays, months, quarters or seasons) could be added to account for seasonality of gas prices. Regarding specification of the model, as far as input data are of time series nature, it is important to test for stationarity of variables and if they are stationary – test for cointegration between dependent and independent variables should be made to choose the final model specification.

CHAPTER 4. DATA

As mentioned in the previous section, the research is primarily based on gas prices data and information about transaction costs associated with the transaction. Therefore, the description of data will be divided into two parts.

4.1. Description of transaction costs

As mentioned in Chapter 3, the are 3 key components of transaction costs for operations considered in this research: transportation cost, storage-related cost and interest cost.

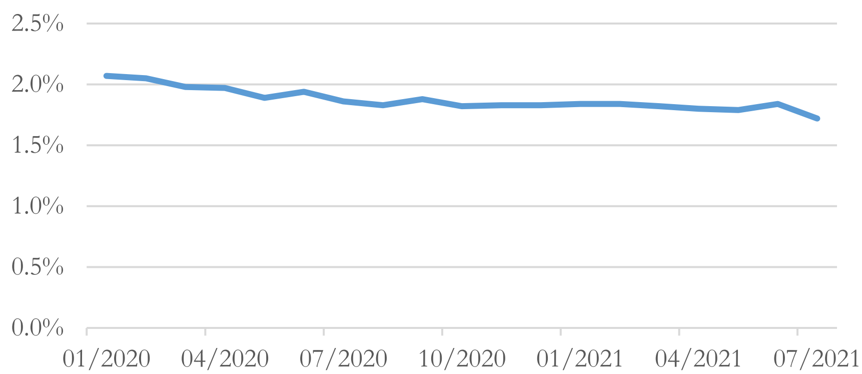
Transportation costs include entry- and exit- fees, paid to TSO of the countries through which the gas is transported. In 2020-2021, the transaction costs were the following:

- 2.77 EUR/MWh to transport gas from Austria to Ukraine via Slovak Republic, or
- 0.6-1.2 EUR/MWh to transport gas from Hungary to Ukraine (the price of Hungarian TSO varies through year), and
- 1.44-2.86 EUR/MWh to transport gas from Ukraine to Austria via Slovak Republic (the amount depends on the period of booking of capacity, if you book capacity for a year, you pay lower price comparing to monthly booking)

Storage-related costs include injection fee, storage fee and withdrawal fee. Injection and withdrawal fee sums to 0.7-0.8 EUR/MWh (from July 2020, Ukrtransgaz decreased the withdrawal fee significantly, so the total amount decreased). The storage fee is calculated based on the number of days in storage and amounts to 0.27 EUR/MWh for the year of storage (0.0007 EUR/MWh per day).

As described in Chapter 3, interest rate on revolving loans and overdrafts issued to non-financial corporation (NFC) in EUR is used as the interest rate. The Figure 6 illustrates historical development of the level of this interest rate, and during 2020-2021 this rate was on average 1.87%. With this level of interest rate, the interest cost (incl. both interest on transaction costs and on the spot price) varies in the range from 0.01 EUR/MWh (minimum for M+1 forward) to 1.34 EUR/MWh (max for S+3 forward).

Figure 6. Interest rate on revolving loans and overdrafts issued to NFC in EUR, %



Source: European Central Bank

Summarizing all the described above, the transaction cost is an easy-forecastable element because it is relatively stable over time and mostly pre-determined. The latter is derived from the fact that the largest share of transaction cost is comprised of transportation cost, which is determined in advance by TSO operators. Thus, this component of the arbitrage profit calculation is not likely to become a source of unexpected change that result arbitrage.

Moreover, it is important to mention that the data availability on transportation costs is much grater than for the period 2020-2021 than before. This, as well as the fact that in 2020 Ukrainian TSO introduced “short-haul” regime that decreased entry/exit fees from Ukrainian side by almost 68% for the operations type under analysis (import-storeexport), subsequent analysis of actual availability of arbitrage is based on data for the period 2020-2021.

4.2. Description of natural gas prices

As described before, CEGH is the basic gas hub for this research. At this exchange, deliverable contracts with different maturity are traded, including day-ahead (DA), month-ahead (M+1, as well as M+2, M+3), quarter-ahead (Q+1, Q+2), gas season-ahead (S+1, S+2, S+3) and year-ahead (Y+1). The data set includes gas prices since mid-2012, except for Y+1, data on which is available for the period from mid-2015.

In the Tables 1 and 2 the descriptive statistics of a spread between forward and day-ahead prices at CEGH are presented (for all forwards except Y+1 – since mide-2012, for Y+1 product – since mid-2015). To account for seasonality of gas prices, the sample was divided to Winter (October-March) and Summer (April-September).

The spread distribution shows that the median spread during Winter is typically around zero, while median spread during Summer is a bit higher. Taking into account the level of transaction costs indicated in the previous section (for AU-UA-AU route – around 6 EUR/MWh), we see that the arbitrage is rarely available during Winter, literally – we can expect it in less than 5% of the days (95th percentile < transaction cost) regardless of the type of a forward contract.

Table 1. Descriptive statistics of difference between forward and day-ahead price at CEGH during Gas Winters in 2012-2021, EUR/MWh

Indicator	M+1	M+2	M+3	Q+1	Q+2	S+1	S+2	S+3	Y+1
Max	6.74	8.59	9.66	9.46	8.36	8.34	10.24	9.19	9.08
95th percentile	0.66	1.08	1.16	1.09	0.84	0.85	3.88	3.83	4.57
Q3	0.09	0.19	0.22	0.20	0.03	0.00	1.28	0.35	0.38
Median	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.00
Average	-0.01	0.09	0.05	0.03	-0.44	-0.43	0.92	-0.30	0.36
Q1	-0.09	-0.07	-0.14	-0.13	-0.69	-0.64	0.00	-1.03	-0.37
Min	-41.19	-41.93	-41.99	-41.70	-41.65	-41.68	-40.83	-42.66	-42.11

Table 2. Descriptive statistics of difference between forward and day-ahead price at CEGH during Gas Summers in 2012-2021, EUR/MWh

Indicator	M+1	M+2	M+3	Q+1	Q+2	S+1	S+2	S+3	Y+1
Max	3.55	7.66	9.25	8.30	9.98	9.08	8.89	10.73	9.54
95th percentile	0.66	2.59	4.17	5.59	7.43	6.62	6.77	8.63	7.35
Q3	0.03	0.27	0.77	0.53	2.43	2.24	1.92	3.36	2.01
Median	0.00	0.00	0.03	0.06	0.50	0.49	0.00	0.51	0.00
Average	0.04	0.48	0.97	0.98	2.16	2.12	0.72	1.92	1.18
Q1	-0.11	-0.05	0.00	0.00	0.00	0.00	-0.51	0.00	0.00
Min	-3.35	-3.65	-3.70	-3.60	-2.79	-2.30	-17.43	-17.40	-13.53

Table 2 illustrates that in contrast to the situation with distribution of spreads during Winter, during Summer the spreads are significantly larger, so in further analysis we can expect the arbitrage to be available. 95th percentile shows that for all contracts with maturity Q+2 or larger arbitrage is more likely to be observed comparing to the Winter. One more valuable insight is that the longer maturity of the contract, the higher we can expect the 95th percentile of spreads to be. For monthly contracts, forward price is typically very close to the spot price, so arbitrage using Ukrainian UGS typically is not economically viable. Thus, arbitrage opportunities are more likely to be found during Summer and for forward contracts with longer maturity.

As mentioned in the previous section, the analysis of actual availability of arbitrage will be based on gas prices during the period of 2020-2021 (till the middle of August 2021). The descriptive statistics of the spot (day-ahead) price during this period is presented in the Table 3, information about 2019 was added for compairson.

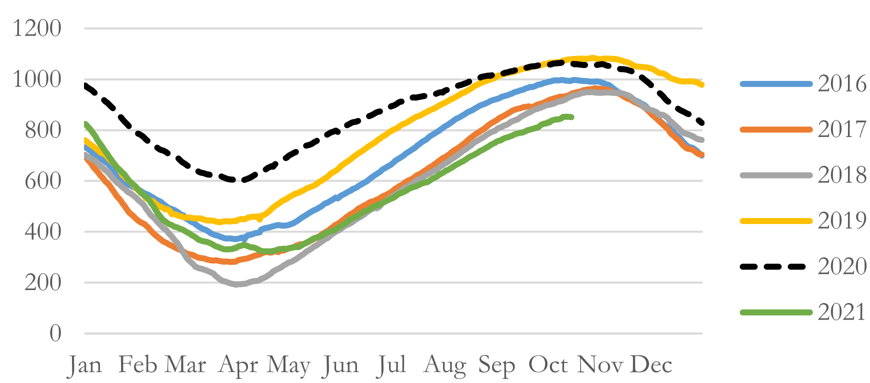
Table 3. Descriptive statistics of day-ahead price at CEGH in 2019-2021, EUR/MWh

Indicator	2019				2020				2021		
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Average	**19.4**	**15.5**	**11.2**	**13.1**	**10.7**	**6.7**	**9.0**	**13.9**	**18.3**	**25.4**	**39.5**
Stand. Deviation	2.2	2.0	1.0	2.1	1.3	1.1	2.1	1.4	1.5	3.7	4.3
Min	15.7	11.6	9.3	9.4	7.8	4.7	6.1	11.6	15.9	19.5	32.4
Lower quartile	18.0	14.0	10.4	11.3	10.1	5.9	6.7	12.8	17.2	22.2	35.6
Median	18.9	15.6	11.1	13.1	10.5	6.5	8.8	13.7	18.3	25.5	39.6
Upper quartile	21.8	17.2	11.9	15.0	11.7	7.7	11.2	14.4	19.0	27.9	42.4
Max	22.8	18.8	13.3	16.9	13.3	8.6	12.3	17.9	25.2	34.9	47.3

According to Table 3, gas price in 2020 followed a typical seasonality pattern: lower price during Summer and higher price during Winter months, but during first half of a year prices was around two times lower than in 2019, which is an evidence of a weak gas demand driven by COVID-19 and related restrictions. This situation seems to be conducive to the aritrage opportunities availability because if the market is oversupplied, and market participants expect rebound of demand in the future, then forwards could be traded with significant premium to the spot price, which enables arbitrage using gas storage. On contrary, the average quarterly prices in 2021 exhibited rather non-typical behavior, in particular – Q2 price was higher than Q1, and Q3 price was higher than Q2. This situation was a result of unexpectedly strong demand for gas in the first half of 2021, primarily driven by faster than expected rebound of economic activity in the world economy and restricted flexibility of gas supply in Europe. From the point of view of arbitrage profit, this situation is not conducive to the presence of arbitrage opportunities, because if the spot price is larger than the forward one due to short-term scarcity of supplies, arbitrage is not possible.

Figure 7 demonstrates the amount of gas stored in gas storages of Europe, excluding Ukraine (as published by authors, AGSI+). We can see that throughout 2020, level of stock was higher than its usual level during previous years, but since May 2021 it became significantly below the historical average, which supports the conclusions above.

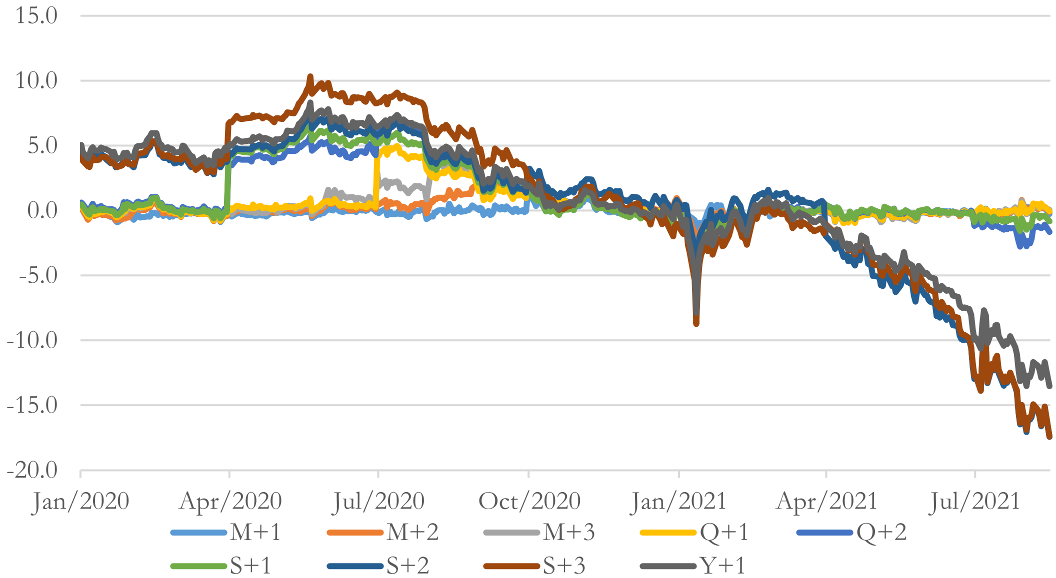
Figure 7. Amount of gas stored in the gas storages of Europe (excl. Ukraine), TWh



Source: agsi.gie.eu

To proceed, it is important to go back to the analysis of spreads between forward and spot price. On the Figure 8, spreads between forward contracts with different maturities and spot prices are plotted based on CEGH data for 2020-2021.

Figure 8. Spread between forward and spot prices at CEGH during 2020-2021, EUR/MWh

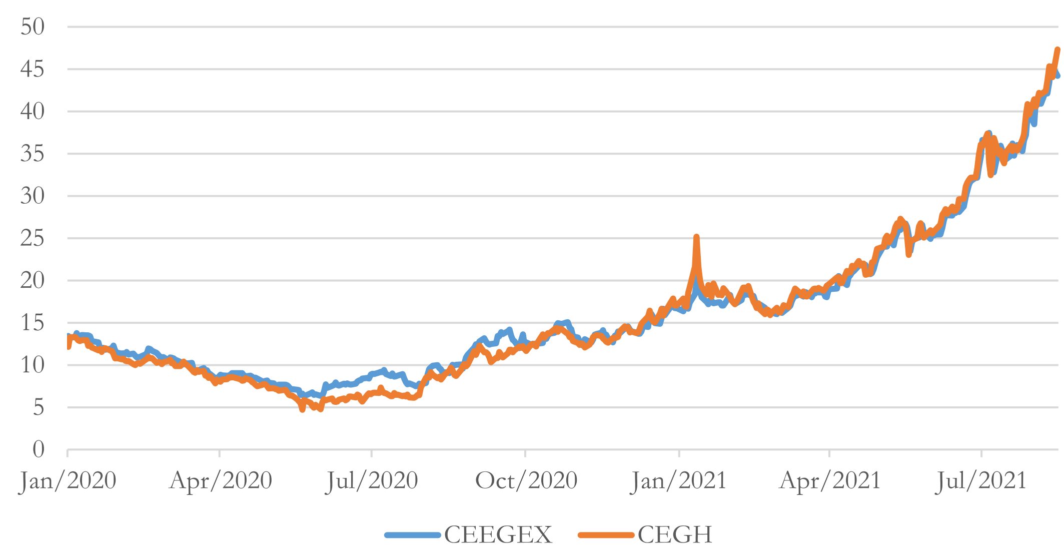


From Figure 7 it is clear that for some forwards (S+1, S+2, S+3, Y+1), arbitrage was available for quite a long time during Summer 2020 as a result of an oversupplied market. Level of spread for Q+1 and Q+2 forwards was also quite high during this period, but the exact judgment about availability of arbitrage could be derived only from more precise estimation that follows. Also, as assumed above, arbitrage in Q2 and Q3 is barely possible due to unexpectedly low levels of gas stock in Europe and expectations of market participants that the situation will normalize since Summer 2022 (S+2, S+3 and Y+1 forwards are traded at discount to the spot gas price).

The last important input dataset that was used is the spot price of Hungarian gas market – CEEGEX – to estimate potential arbitrage profit with the gas from the market with lower liquidity and lower transportation cost (because Hungary is a direct neighbor of Ukraine).

Spot (day-ahead) prices on the Hungarian market was obtained from official website of CEEGEX are plotted on the Figure 9 with day-ahead price at CEGH. It could be seen that despite both prices are highly correlated and are traded approx. at the same level, during Summer 2020 CEEGEX was traded at premium to CEGH, so the lower transportation cost from Hungary could be partially or fully covered by the higher spot price during that period. Probably, the availability of arbitrage was driving premium of Hungarian gas price to CEGH during that period, because European gas storages was at record levels in Summer 2020, so gas flows was redirected to the Ukrainian UGS through Hungarian market.

Figure 9. Day-ahead price of natural gas in Hungary (CEEGEX) and Austria (CEGH) in 2020-2021, EUR/MWh



Source: ceegex.hu

CHAPTER 5. RESULTS

5.1. Evidence on arbitrage opportunities during 2020-2021

During research process, opportunities to earn arbitrage profit between 9 pairs of spot-forward prices during 2020 and 8 months of 2021 were examined. The research has shown that in the case of AU-UA-AU route, arbitrage was possible only with 5 forward products – Q+2, S+1, S+2, S+3, Y+1. In the case of HU-UA-AU route, arbitrage was also possible with Q+1 product, but only for a one day (out of 411 days that were examined). Table 4 summarizes the results obtained.

Table 4. Description of arbitrage opportunities available during 2020-2021

Indicator	M+1	M+2	M+3	Q+1	Q+2	S+1	S+2	S+3	Y+1
Austria-Ukraine-Austria									
Count of arbitrage opportunities, days (out of 411 days)	0	0	0	0	2	18	49	94	65
Max profit, EUR/MWh	n/a	n/a	n/a	n/a	0.36	0.97	1.77	4.19	2.80
Average profit, EUR/MWh	n/a	n/a	n/a	n/a	0.33	0.31	0.51	1.88	1.28
Max profit, % of initial investment	n/a	n/a	n/a	n/a	4%	12%	21%	50%	34%
Average profit, % of initial investment	n/a	n/a	n/a	n/a	3%	4%	6%	19%	14%
Hungary-Ukraine-Austria									
Count of arbitrage opportunities, days (out of 411 days)	0	0	0	1	7	58	84	107	130
Max profit, EUR/MWh	n/a	n/a	n/a	0.2	0.38	1.79	2.50	4.60	3.45
Average profit, EUR/MWh	n/a	n/a	n/a	0.2	0.17	0.62	0.74	2.52	1.29
Max profit, % of initial investment	n/a	n/a	n/a	1%	4%	23%	32%	59%	44%
Average profit, % of initial investment	n/a	n/a	n/a	1%	2%	7%	8%	27%	14%

In Table 4, initial investment is determined as sum of spot price, cost of transporting gas from point of purchase to Ukrainian gas storage, cost of injection to the gas storage and a storage fee. Other costs (withdrawal fee, cost of transporting gas from the storage to the country of sale, interest) are paid at the end of the transaction, apprixImately at the moment when the revenue is received, thus we can expect these costs to be covered from revenue and do not account for them as the part of initial investment.

From the Table 4, the following conclusions can be made:

- As assumed in Chapter 4, arbitrage opportunities were available primarily for products with high maturity: from Q+1 to Y+1. The number of days for which arbitrage profit was available is the largest for S+3 product in the case of the first route (AU-UA-AU), but in the case with gas from Hungary, operations with Y+1 had wider "window of opportunities" – there were 130 trading days during which arbitrage was possible.

- The average arbitrage profit varies depending on the route and maturity, but in both routes the largest average profit was obtainable using S+3 product: 19% and 27% for AU-UA-AU and HU-UA-AU routes correspondingly.

- The average return on the Hungarian route was higher that on the AU-UA-AU route: the weighted average return of all arbitrage opportunities during analyzed period was 15% in the first case and 13% in the second one. The number of arbitrage opportunities (namely, the count of days during which the arbitrage was possible) is also higher for HU-UA-AU route: 387 observations (out of 3 699 possible) comparing to 228 in the case of Austrian route. This information could be interpreted as a supportive evidence to the conclusions made by Nick (2016), that difference in liquidity between markets could result in availability of arbitrage. In this case, lower liquidity at Hungarian gas exchange (CEEGEX) is associated with a greater availability and larger amounts of arbitrage profits comparing to the transaction that is based solely on CEGH prices (Austrian gas exchange with greater liquidity).

It is important to note that these calculations do not account for fixed costs that could be associated with the identification and execution of this deal, as well as for payroll costs, fees associated with the access to the exchanges and other administrative costs – the analysis was built on the marginal cost basis, that is for the companies that are already operating in these markets. But even accounting for this, the profit that traders were able to obtain during Summer 2020 from the deals described above is so significant that these costs should be completely covered.

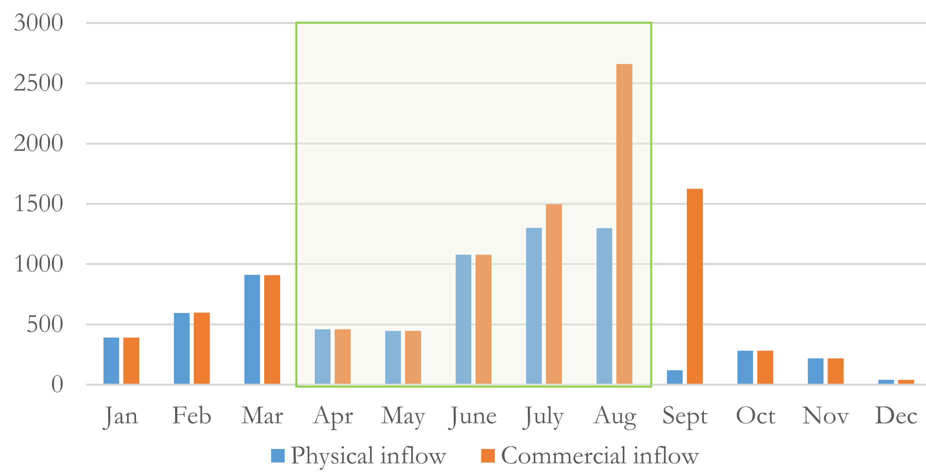
S+3 forwards are the most profitable ones for both routes, though it is important to understand what amount of initial investment such transaction would require. The rules for seasonal products at CEGH Exchange Market are that the product is sold at base load, with a minimum trade size of 1 MW. It means, that for Winter seasonal product the requirement is to purchase 1*182*24=4 368 MWh (or 4.37 GWh) of gas. For example, on May 29th, 2020, the spot price at CEGH was 5.29 EUR/MWh, and the transportation cost from Austria to Ukraine – 3.64 EUR/MWh incl. cost of injection and storage at Ukrainian UGS. In total, it requires 4 368 * (5.29+3.64)=38 978 EUR of initial investment. Given the forward price of 14.65 EUR, and accounting for withdrawal and transportation cost to Austria (2.23 EUR/MWh), the remaining margin of 14.65-5.29-3.64-2.23=3.5 EUR/MWh will be used to pay out 0.28 EUR/MWh of interest and the trader will end up with a profit of 3.22 EUR/MWh, or 14 060.5 EUR in total. This operation at AU-UA-AU route is associated with an unlevered internal rate of return (IRR) of 23.1% (without interest cost).

Such high unexploited arbitrage profits indicate that some market imperfections or technological constraints are responsible for this revealed market inefficiency. One potential explanation is that a minimum contract size to exploit these arbitrage opportunities is too large, and the corresponding positions could not be taken because the amount of gas traded at the exchange during the day is lower than 4.37 GWh. However, the average daily amount of deliverable OTC (over the counter) contracts at CEGH in 2020 was around 570 GWh, so the minimal amount of an arbitrage deal is less than 1% of the average daily traded amount. So, such a deal should not have a significant effect on prices. Therefore, the market depth does not seem to be a reason why the arbitrage is possible.

Another restriction might be due to constrained transportation capacity, namely – capacity of interconnection points between countries. The physical interconnection between Ukraine and Slovak Republic that allows for physical gas inflow to Ukraine is located at Budince point, and it has 27 mln m^3 of firm (guaranteed) capacity and 15.5 mln m^3 of interruptible capacity, so the total daily capacity is 42.5 mln m^3, or approximately 450 GWh, which is significantly larger than the minimal amount of arbitrage trade.

The actual physical and commercial flows of gas in 2020 are plotted at Figure 10. The months during which arbitrage was possible are marked with green area.

Figure 10. Physical and commercial gas flows from Slovak Republic to Ukraine in 2020, mln m^3



Source: tsoua.com

It is clear that during April-June imports were lower than the physical capacity (42.5 mln m3 per day ~ 1300 mln m3 per month). In fact, during April and May physical flows were around 450 mln m^3 per month, which is even lower than firm capacity (27 mln m3 per day ~ 820 mln m3 per month), so the capacity was not an issue during those months. On contrary, during July and August, the physical flow was close to the maximum capacity. Moreover, since August Eustream (Slovakia's TSO) agreed to start the virtual reverse of max. 60 mln m^3 per day at Veľké Kapušany interconnection point, which resulted in the fact that commercial flows were 2 times higher than physical ones in August. Commenting on this situation, S&P in the article "The 'U' factor: Ukraine's growing role in Europe's natural gas market" published in November 2020 wrote: "So when Velke Kapusany reverse flow nominations for Monday Aug. 3 jumped almost sevenfold from the previous Friday to 44 million cu m [m^3], traders suddenly realized that of the 110 million cu m expected to enter Slovakia in forward physical mode, only 66 million cu m would actually arrive, a major and unexpected supply cut.".

Table 5 illustrates characteristics of arbitrage opportunities with S+3 forward by months during Summer 2020. During April-August 2020, 94 arbitrage opportunities with S+3 forward appeared – it accounts for all the arbitrage opportunities with this product observed during 2020-2021 (see Table 4). Also, it is important to notice that during April-July, arbitrage was available during each trading day of a month, but in August (the month when virtual reverse at Veľké Kapušany point was launched) number of arbitrage opportunities and amount of average profit significantly decreased.

Table 5. Description of arbitrage opportunities with S+3 forward that was available during Gas Summer 2020 at AU-UA-AU route

Indicator	April	May	June	July	August
Count of arbitrage opportunities, days	20	19	22	23	10
Number of observations, days	20	19	22	23	20
Max profit, EUR/MWh	1.07	4.19	3.72	3.01	0.60
Average profit, EUR/MWh	0.79	2.30	2.65	2.43	0.33
Max profit, % of initial investment	9%	50%	44%	30%	5%
Average profit, % of initial investment	7%	25%	28%	24%	3%

Summarizing, most arbitrage opportunities that arose during 2020-2021 were available during a limited period of time – from April till August. During this period, no significant market liquidity or capacity restrictions were in place, so they are not likely to be a reason why arbitrage was possible. It is important to pay attention to the context of a period when the situation was developing – quarantine measures imposed in all countries of the region, seriously affected operations of companies. The reasons why traders did not enter the described arbitrage deals in April-May (when a significant amount of interconnection capacities was not used) could include various factors, from interruption of usual business processes with remote work to problems with liquidity that arose for all energy companies with long positions in commodities due to unprecedented decrease of prices on energy commodities. Also, it is important to notice that usage of new short-haul service was not familiar for European traders before 2020. During the first quarter of 2020, under short-haul service only 29.6 mln m^3 was imported (out of 1896,7 mln m^3 imported from the Slovak Republic), so we can assume that some institutional-related constraints still could have been a barrier for traders in April-May. Furthermore, unprecedented uncertainty that arose during that period could also become a reason for banks to restrict the issue of new loans to trading companies, and traders – to temporarily hold off from the use of equity capital.

As we can observe from Figure 10, in June traders significantly increased imports to Ukraine from the Slovak Republic, and then in July they utilized all available physical capacity at Budince point. Despite that, Table 5 shows that there still were plenty of arbitrage opportunities in July, so that amounts of physical import were not enough for the market to reach equilibrium. It was particularly obvious in August, when virtual reverse at Veľké Kapušany point was enabled, and market participants imported 2.7 bln m^3 from the Slovak Republic to Ukraine, from which 1.7 bln was imported under "short-haul" regime. This resulted in a significant decrease in arbitrage profits in August, namely to 0.33 EUR/MWh on average during 10 profitable days (out of 20), compared to the average profit of 2.43 EUR/MWh that were available each day during July. So, we can conclude that a significant increase in gas flows from the Slovak Republic to Ukraine in August is associated with a significant decrease in arbitrage availability on the route Austria-Ukraine-Austria.

Thus, taking into account all the mentioned above and the fact that in September the market reached the state which does not allow for arbitrage, we can conclude that availability of arbitrage opportunities during Summer 2020 was rather an expression of the institutional imperfection of the gas market rather than market inefficiency.

5.2. Factors contributing to arbitrage profits

As described in Chapter 4, the key determinant of arbitrage opportunities is the dynamics of spread between forward and spot price, and one of the key factors that could drive change of this spread is the ratio between current level of gas in gas storages and historical average of gas in storage during past years on this day.

For modelling purposes, the spread between Season+3 and day-ahead prices at CEGH was chosen as the arbitrage profit variable, because arbitrage between this pair was the most frequent and profitable during 2020-2021. To account for different situations possible at the market, prices from May 2015 till August 2021 were used.

The pre-estimation tests showed that both spread and relative level of gas in the storage are stationary, and integrated of order 1. Furthermore, these variables do not appear to be cointegrated, so the model could not be estimated in levels. Thus, variables were differenced to achieve stationarity of time series, and further estimation was based on first differences.

Various specifications of the model were tested, including attempts to incorporate variables that reflect gas storage level (for Austria only or for European Union, in TWh or in % of maximum capacity), seasonality variables (dummy variables for Winter/Summer, months, quarters, weekdays), different number of lags of dependent variable (differenced spread). Based on the Akaike information criterion, the model with the following set of independent variables was chosen: 5 lags of spread (differenced), deviation of level of gas storage in EU in % of maximum capacity from historical average (differenced) and dummy variables for weekdays (Monday through Thursday). The final specification of the model is the following:

$$\Delta Spread_t = \alpha_0 + \alpha_1 L(\Delta Spread_t) + \alpha_2 L^2(\Delta Spread_t) + \alpha_3 L^3(\Delta Spread_t) + \alpha_4 L^4(\Delta Spread_t) + \alpha_5 L^5(\Delta Spread_t) + \alpha_6 \Delta EU\_storage\_\%_t + \alpha_7 Monday_t + \alpha_8 Tuesday_t + \alpha_9 Wednesday_t + \alpha_{10} Thursday_t + \epsilon_t \quad (5)$$

The estimated coefficients are shown in Table 6. Distribution of residuals of a model is shown in Appendix A. Post-estimation tests results are presented in Appendix B.

Table 6. Results of the linear model estimation

Variable	Coefficient	Standard error
lag(d_spread, n = 1)	-0.115***	0.025
lag(d_spread, n = 2)	-0.055**	0.026
lag(d_spread, n = 3)	-0.082***	0.026
lag(d_spread, n = 4)	-0.089***	0.026
lag(d_spread, n = 5)	-0.068***	0.026
d_EU_d	12.371***	4.308
Mon	-0.090**	0.039
Tue	-0.081**	0.038
Wed	0.043	0.038
Thu	0.005	0.038
Constant	0.007	0.027
Notes	***Significant at the 1 percent level. **Significant at the 5 percent level. *Significant at the 10 percent level.	

Post-estimation tests showed that despite residuals not being distributed normally (due to large deviation from the normal distribution at tails – see Appendix A), they are distributed independently and identically, and they do not exhibit serial correlation (see Appendix B). Given that the sample size is large (1573 observations), normality is not an absolute requirement for distribution of residuals, so the model is fitted well as far as it passes test for absence of serial correlation and test for identity and independence of distribution.

The following conclusions could be drawn based on estimated coefficients presented in Table 6:

- If positive deviation of spread appears due to market movements, it is likely to have a downward trend next days. Namely, if the spread was 0 during the week, but today it became 10 EUR/MWh due to some market factors, tomorrow the spread is expected to decrease to 8.845 EUR/MWh, in a day after tomorrow – to 7.216, in two days – to 6.117 EUR/MWh and so on (ceteris paribus). In 13 trading days, 90% of a chock is expected to disappear, and in 20 trading days (equivalent to a calendar month), spread is expected to become 0.2 EUR/MWh (ceteris paribus). This pattern indicates that market participants tend to exploit arbitrage opportunities if they arise, which results in narrowing of the spread. Thus, we can conclude that traders' behavior is economically rational, and the market is likely to be efficient. However, due to some reasons, execution of the arbitrage-exploiting deals takes some time, so the market institutional structure is likely to be imperfect, because it does not allow to exploit arbitrage immediately.

- Increase of fullness of gas in storages across Europe (comparing to 5-year average) comparing to the last trading day is likely to increase spread between S+3 forward price and spot price. In particular, if yesterday the fullness of gas storage in Europe was 60% given historical average of 70% (so the relative fullness is -10%), and today it became 61% given the same level of historical average (so the relative fullness is -9%), then the spread is likely to be 0.1237 EUR/MWh higher than average (average spread is 0.81 EUR/MWh). This fact provides supportive evidence to the assumption that increase in gas storages fullness has bearish effect on spot gas prices, so on increasingly oversupplied market we can expect the spread to increase continuously. But it is important to mention that during 2015-2021 1st percentile of values of this variable was -0.62%, median was -0.01%, and the 99th percentile was 0.87%. So, variation of this factor on a daily basis is not large, and we should not expect this factor to contribute significantly to the level of spread. Thus, despite this factor appeared to be statistically significant in the estimated model, it was not appeared to be economically significant.

- On Monday and Tuesday, the spread is likely to be 0.090 and 0.081 EUR/MWh lower than on Friday (respectively). So, these coefficients mean that if arbitrage profit existed on Friday, it is likely to decrease at the beginning of the next week. This could potentially be explained by the fact that during weekend traders have time to make more precise analysis of information obtained at the end of last week and during weekend, and at the beginning of the week the market is more liquid that results in narrowing of the spread. But analysis of daily traded volumes at CEGH during 2018-2020 showed that average volume traded during Mondays and Tuesdays is around 1% lower than during Wednesday-Friday. Thus, this phenomenon is likely to be determined by other factors, for example by behavioral ones (e.g., "January effect", or "weekend effect" on stock markets), which lies outside the scope of this analysis.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

Ukrainian gas market transformation, reformation, and liberalization started in 2014, is not finished yet. Despite this fact, dramatic changes happed with the Ukrainian gas transmission system during this period, including unbundling of the Gas Transmission System Operator of Ukraine from Naftogaz of Ukraine, harmonization of legislation with the EU, promoting transparency of the gas market, and introduction of new storage-related services that created new opportunities for European gas traders.

In particular, for traders who are willing to import gas to Ukraine, store it in the gas storage and then re-export it to the European Union, transaction costs became on average four times lower after the introduciton of the new "short-haul" service by Ukrainian TSO in 2020. This naturally made operations with Ukrainian gas storage more profitable for traders. Combined with a dramatic oversupply on the European market happened in Summer 2020 due to COVID-related restrictions on economic activity, greater availability of Ukrainian gas storage provided market participants with one more option to store gas in till a rebound of economic activity occurs. In such a situation, when the spot prices are low due to oversupply and forward prices are significantly higher because market participants expect the recovery of economic activity, intertemporal arbitrage was possible.

Analysis of availability of arbitrage using Ukrainian gas storage was conducted based on gas prices at CEGH – the most liquid spot and derivatives gas exchange in Central and Eastern Europe, located in Austria. We analyzed the following type of arbitrage transactions: simultaneously purchase gas at CEGH spot market and sell the same amount of gas at CEGH forward market, transport gas to Ukraine for storage, and on the delivery date – transport it back to Austria. These trades were assumed to be wholly financed with debt. To check for the potential difference in profits between markets with different liquidity, an additional route was considered: simultaneously purchase gas at CEEGEX spot market (Hungary) and sell it at CEGH forward market, transport gas to Ukraine for storage, and on the delivery date – transport it to Austria.

Our investigation of data for the period from the beginning of 2020 till August 2021 yielded the following results: arbitrage opportunities were available at both routes that were examined (Austria-Ukraine-Austria and Hungary-Ukraine-Austria); the arbitrage was available with quarter-ahead, season-ahead, and year-ahead forward products during, mostly during April-August 2020. The amount of arbitrage profit that was possible to earn using these zero-risk trades was: 1.28 EUR/MWh and 1.39 EUR/MWh for AU-UA-AU and HU-UA-AU routes respectively. These profits correspond to 13.2% and 14.9% of return on the initial investment (not annualized) respectively. As we can observe, the arbitrage with gas purchased in Hungary on average provided traders with higher profits, so we can conclude that in this case difference in liquidity between Austrian and Hungarian gas exchanges, in fact, enabled traders to get higher arbitrage profits.

Furthermore, the fact that the arbitrage was possible during such a long period of time does not imply that the market was inefficient. Our analysis showed that despite the absence of capacity and liquidity constraints in April and May, market participants' response to the arbitrage availability took about 2 months: first arbitrage opportunities appeared in the beginning of April 2020, and in June amount physical flow of gas from the Slovak Republic (part of a route from Austria) to Ukraine increased significantly. During July traders fully utilized potential of phyiscal interrconnection point from the Slovak republic to Ukraine (1.3 billion m^3), but the arbitrage still existed, because traders faced capacity constraints. But from August 2020, Eustream (TSO of the Slovak Republic) allowed for virtual reverse at Velke Kapusany interconnection point, which resulted in doubling of commercial gas flows from the Slovak Republic to Ukraine – it reached 2.66 billion m^3, of which only 1.3 billion m^3 was physically imported to Ukraine. This change was associated with rapid decrease of arbitrage profits at this route, so we conclude that market participants behaved economically rational and exploited arbitrage as soon as they were able to. Taking into account that short-haul service was introduced only at the beginning of 2020 and not many traders were able to try using it before April 2020, and given that April and May 2020 were months when the most severe COVID-19 related restrictions were imposed (which resulted in disruption of usual business processes, negatively impacted companies' creditworthiness etc.), we conclude that availability of arbitrage during this period was rather an indicator of the institutional imperfection of the market, rather than market inefficiency.

This conclusion was supported by econometric modelling of a spread between Season+3 forward price and the spot price at CEGH based on data from May 2015 till August 2021. The analysis of the spread dynamics could be used as a proxy for analysis of the arbitrage profit dynamics because other factors that contribute to the arbitrage profit amount are rather of a constant nature. Our modelling showed that the key determinant of the change in the spread is its autoregressive terms, and the spread dynamics exhibits a mean reversion pattern. Namely, 90% of a shock (unexpected deviation of the spread from average) are likely to disappear within the next 13 trading days after a shock.

Our econometric modelling also showed that spread between S+3 forward and the spot price tends to be lower on Monday and Tuesday compared to Friday by approximately 0.08-0.09 EUR/MWh. Within our research, we were not able to identify the reason for such a pattern, so underlying for this dynamics (institutional specifics of a gas market, behavioral or other factors) could be a topic for further research.

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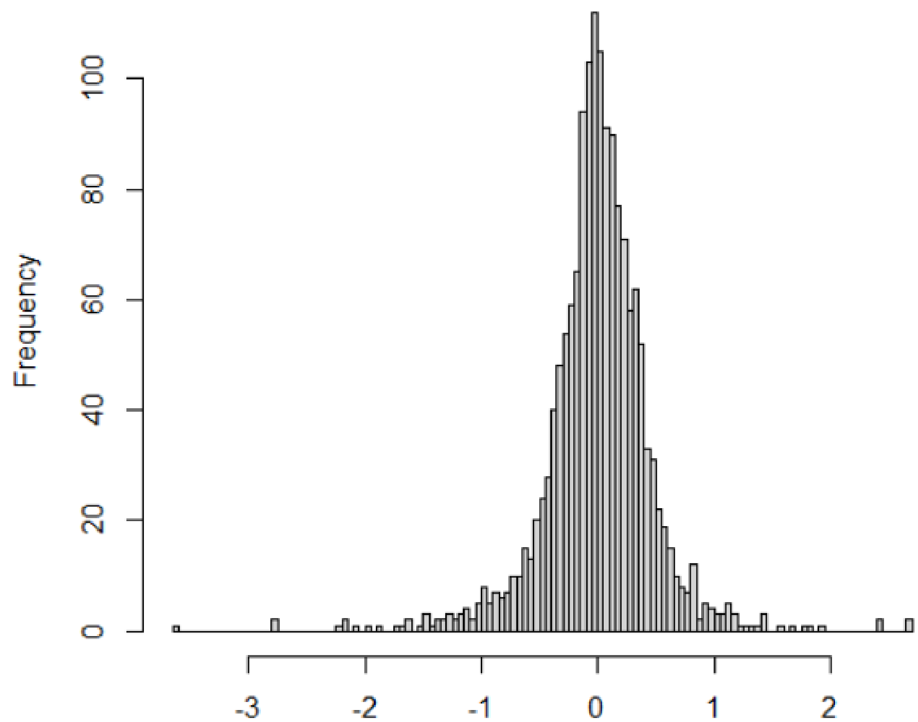
APPENDIX A
LINEAR MODEL RESIDUALS DISTRIBUTION



APPENDIX B

POST-ESTIMATION TESTS RESULTS

Box-Ljung test

X-squared = 3.1978, df = 7, p-value = 0.8661

Shapiro-Wilk normality test

W = 0.90527, p-value < 2.2e-16

Rank von Neumann Test for Lag-1 Autocorrelation (Normal Approximation)

z = -0.66797, p-value = 0.5042

alternative hypothesis: true rho is not equal to 0

sample estimates:

rho

0.003744189