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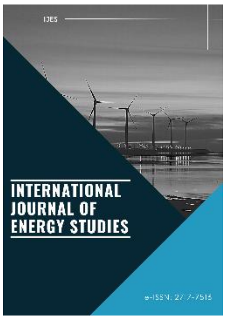

Research Article

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Are global natural gas markets integrated?

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Highlights

- The study examines the dynamics of natural gas market as a transition vehicle to full renwable enegy market, looking into the interaction of global natural gas market.
- Overall, the findings obtained using the BEKK and DCC models make a significant contribution to understanding the dynamics of global natural gas markets and the interactions between these markets.
- A combination of econometric models such as ARDL, BEKK GARCh, and DCC GARCH are used to identify the nature of global major gas hubs.

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ABSTRACT

This study explores the degree of integration and volatility spillovers among the leading natural gas markets in the world, namely the United States (Henry Hub), the United Kingdom (National Balancing Point, NBP), and Japan (Japan Korea Marker, JKM). Using a combination of ARDL, BEKK-GARCH, and DCC-GARCH models on daily closing price data covering the period from July 2014 to November 2023, the analysis aims to determine whether natural gas markets operate in an integrated global structure or maintain regionally segmented dynamics. The research is motivated by the increasing importance of natural gas in the global energy mix, transition to green energy, its role in energy security, and the impact of geopolitical and economic shocks on price stability.

The findings reveal notable asymmetries across markets. The Japanese and British hubs are strongly interconnected, reacting intensively to both their own past shocks and external shocks originating from each other. Dynamic correlations between Japan and the UK remain persistently high, suggesting a tight long-term linkage between Asian and European markets. In contrast, the U.S. market exhibits a more insulated structure, with shocks from Henry Hub showing limited spillover effects on the UK and Japanese markets. While volatility from Japan spills over significantly to both NBP and Henry Hub, the reverse transmission from the U.S. is weak, underscoring its relatively independent position in the global natural gas system.

These results provide evidence that the global natural gas market is only partially integrated. Whereas Europe and Asia demonstrate strong interdependence, the United States remains more detached, reflecting differences in market structure, pricing mechanisms, and regional policy frameworks. The study contributes to the literature by offering comprehensive insights into the asymmetric nature of volatility transmission and market linkages, thus clarifying the dynamics of global gas hubs in the post-2014 energy landscape. From a policy perspective, the results highlight the importance of regional cooperation between Asian and European markets, while also underlining the strategic autonomy of the U.S. in global energy trade.

Keywords: Energy markets, Integration, DCC GARCH, ARDL, BEKK

1. INTRODUCTION

The concept of market integration is critical to understanding the dynamics of global trade and economic efficiency. In the context of natural gas markets, integration refers to the extent to which different regional markets can influence each other through demand, and supply price formation mechanisms. This study aims to investigate the level of integration in global natural gas markets by examining the interaction between geopolitical factors, infrastructure, regulatory frameworks and market forces. Specifically, this paper seeks to answer the following research questions:

- To what extent are the U.S., UK, and Japanese natural gas markets integrated?
- Do price shocks in one market transmit to the others, and if so, in which direction and magnitude?
- Are there asymmetries in volatility spill overs among these markets?

Based on these questions, the study tests the following hypotheses:

- $\boldsymbol{H_1}$: Global natural gas markets exhibit partial rather than complete integration.
- $\boldsymbol{H_2}$: The European (NBP) and Asian (JKM) markets are more closely linked compared to the U.S. (Henry Hub).
- $\boldsymbol{H_3}$: Volatility transmission is asymmetric, with stronger spillovers from Japan and the UK to the U.S. market than vice versa.

Market integration refers to how economic markets are interconnected and interact with each other. It examines whether price changes (shocks) in one region led to similar price changes in other regions. For example, when natural gas prices rise rapidly in one country, this price increase is also felt in other countries when market integration is high. This reveals how integrated the markets are and how strong the trade between them is. High integration ensures that price shocks spread quickly and widely [1].

Over the past ten years, natural gas markets have experienced significant transformations. Global deregulation efforts, the restructuring of previously vertically integrated supply chains, and decreasing costs—particularly in the transportation of liquefied natural gas (LNG)—have contributed to the development of a new "international gas market." This new market is set to replace the older regional markets that existed in North America, Europe, and Asia. Additionally, traditional pricing models have been re-evaluated and a shift has been made from long-term natural gas prices, which are often tied to the price of oil, to market-based prices [2].

Global natural gas markets are often regionally isolated because transporting natural gas over long distances is costlier than transporting oil or coal. While oil and coal can be easily transported, infrastructure such as special pipelines or liquefied natural gas (LNG) terminals are required to transport natural gas, which increases the cost of transportation and makes the process more complex. However, the rise of LNG is overcoming these regional barriers and making natural gas a global commodity [3]. Although there is no truly global natural gas market [4] there are many commodity markets around the world [4] and [5].

In the European natural gas market, external suppliers such as Algeria, Norway, and Russia play a crucial role in meeting demand. Russia, in particular, had traditionally supplied a significant share of Europe's natural gas needs until recent geopolitical tensions disrupted this flow. Europe's demand for natural gas remains substantial, especially in industry, heating, and electricity generation. In North America, natural gas production in the United States has increased significantly in recent years, enabling exports to neighbouring countries such as Canada and Mexico, mainly through pipelines. In Asia, the primary exporters of natural gas include Qatar and other Middle Eastern countries, as well as Indonesia, Malaysia, and Australia. Major importers such as Japan, China, and South Korea rely heavily on natural gas to satisfy their growing energy needs. The rapid economic expansion and rising consumption in Asia have intensified the region's role in shaping global natural gas dynamics [6]. Moreover, the gas market in Europe is oligopolistic [7].

The North American gas market is highly competitive with many companies supplying gas from a variety of sources, and this competition provides better prices and services to consumers. The Asian gas market is transforming from a monopoly dominated by Japan to a more diversified structure in which Japan, Korea and China, and up to a certain level Taiwan, are important importers. This diversity reduces the power of a single buyer to control the market and increases competition [8] .

The integration of the USA and Europe in the natural gas market has increased significantly. Since 2018, US-LNG exports to Europe have increased by 2418%. This increase has resulted in only 4.4 billion cubic meters of US LNG arriving in the EU in January 2022. When offered at a competitive price, US LNG plays an important role in increasing diversity and strengthening energy security in the EU. Transatlantic cooperation aims to remove barriers to US LNG exports, develop key infrastructures, and hold regular consultations to strengthen the US's position as a major gas supplier to Europe. Despite stable US LNG export capacity, Asian customers have diverted cargoes to Europe due to higher prices; This demonstrates market dynamics and the potential for greater integration between the US and Europe in the natural gas sector [9]; [10]

To assess the level of integration, consider these factors:

1.1. Price Convergence

Price convergence and natural gas prices in different regions respond quite closely to global supply and demand fluctuations. Natural gas prices constantly fluctuate depending on the balance of supply and demand, changes in production and consumption, geopolitical factors and weather conditions. For example, if there is a global oversupply of natural gas, prices often fall because there is an excess in the market. Conversely, factors such as supply constraints or unexpected increases in demand can raise prices [11].

Convergence between prices in different regions generally depends on supply and demand dynamics, transportation costs and local regulations. For example, an increase in natural gas supply in one region may reduce prices in that region, while prices may rise in another region where there is a lack of supply. However, the costs required to transport the gas also affect prices. Therefore, it can be said that natural gas prices respond closely to global supply and demand fluctuations, although this response can sometimes show regional differences.

In this context, the analysis methodologically begins with the concept of complete convergence, although it presents certain challenges. One key factor to consider is transaction costs, which in this study are defined as the total of transportation, storage, liquefaction, and regasification expenses. These costs hinder the expectation of absolute convergence in gas prices. Instead, this study focuses on testing the relative convergence of price growth. This approach assumes that the combined transaction costs do not consistently rise at a fixed rate over the long term [11]. Relative price convergence suggests that prices will asymptotically approach a linear combination (the error correction term) in the long run. However, for most transoceanic natural gas price pairs, the current level of economic integration is not anticipated to produce stationary error correction terms. Consequently, the presence of relative convergence can be seen as an indication of asymptotic co-integration. This implies that while prices may converge to some degree in the long run, they do not achieve complete convergence.

1.2. Trade Flows

Natural gas supply depends on geopolitical and technical factors, as well as factors that affect demand, such as temperature and economic activities. Therefore, natural gas storage facilities are very important to ensure the balance of supply and demand. Under normal market conditions, storage facilities store excess gas, creating a stockpile for future use. Thus, more expensive production methods can be avoided and a safety buffer can be provided during periods of high demand. This peak usually occurs at certain times of the year. However, during periods of high demand, storage plays an important role when there are no other resources to meet the demand. For example, in Europe during the early period of Covid-19, storage facilities helped reduce production disruptions and avoid negative price fluctuations. In emergency situations, storage facilities act as a buffer against sudden production losses or disruptions in the supply chain due to geopolitical reasons [12].

The flexibility of natural gas trade between different regions can vary depending on many factors. These include countries' natural gas reserves, production capacities, demand levels, infrastructure facilities and political factors. In general, the volume of natural gas trade has a significant impact on the balance of energy demand and supply between countries. If a country's natural gas reserves are low or its production capacity is limited, this country can meet its needs through foreign trade. Trade volume is generally high because natural gas is more easily transportable than other energy sources. However, the flexibility of natural gas trading depends on infrastructure availability and political factors. For example, without infrastructure such as natural gas pipelines or liquefied natural gas (LNG) facilities, trade volume and flexibility may be limited. Additionally, factors such as political disputes, border closures or trade barriers may also affect the flexibility of trade [13].

1.3. Infrastructure Connectivity

The development of pipelines and LNG export/import facilities varies in various regions around the world. For example, significant progress has been made in China, with more than 70,000 kilometres of long-distance gas pipelines and 13 LNG terminals [14]. In the Australasia region, the focus has been on the development of export pipeline systems for LNG projects [15]. Under the Belt and Road Initiative (BRI), the ASEAN region has emerged as a major player experiencing rapid development in LNG trade [16]. However, LNG bunker infrastructure in inland waterways is still in its early stages of development [17]. This diversity reflects differences in regional priorities and needs in the field of energy transportation.

1.4. Regulatory Environment

The impact of regulations on competition and cross-border trade is a complex issue. [18] argues that strict environmental regulations can both hinder and enhance the competitiveness of the sector, depending on the context. In particular, it is possible for companies operating in countries with high environmental standards to gain a competitive advantage. Exploring this issue further, [19] argues that the strength of regulations may be affected by factors such as industry structure and uniqueness of assets. For example, the fact that large-scale companies have more resources and effective lobbying power may result in their favour in the implementation of regulations.

[20] provides empirical evidence on the negative impact of domestic regulations on international trade in the services sector and notes that these regulations can create significant barriers. In particular, it is stated that non-compliance when trading services between different countries may create additional costs and transaction difficulties for service providers. Taken together, these studies highlight the need for regulators to have a detailed understanding of the relationship between competition and cross-border trade. The complexity of this relationship may vary across various sectors and geographic regions, so it is important for policymakers to shape regulatory strategies by taking local conditions and sectoral dynamics into account.

The remainder of this paper is structured as follows. Section 2 reviews the existing literature on global natural gas market integration and volatility spillovers. Section 3 outlines the data and methodology employed in the study. Section 4 presents the empirical results and discusses the findings in light of previous research. Finally, Section 5 concludes with policy implications and suggestions for future research.

2. LITERATURE REVIEW

Based on literature, natural gas markets have been regional due to the difficulties associated with transporting gas over large distances. However, the emergence of liquefied natural gas (LNG) technology has triggered a shift towards a more globalized market structure. The emergence of LNG as a flexible and portable energy source has bridged the physical divide between different markets, potentially leading to increased price convergence and market interdependence [21] and [22]. Additionally, the role of natural gas as a transition fuel in the transition to a low-carbon economy has increased its importance on the global stage. As countries strive to achieve climate goals, demand for natural gas is expected to increase due to its relatively lower carbon footprint compared to coal and oil [23]. This energy policy shift could further integrate markets as countries seek stable and secure sources of natural gas to support energy transitions.

The integration of the global natural gas market emerges as a complex and dynamic process. [24] states that the European market is not fully integrated and emphasizes that market integration in this region has not yet been completed. [25], on the other hand, predicts a significant growth in intercontinental natural gas trade and predicts that prices will remain relatively stable in the main import regions. However, [26] reveals that the international natural gas market is not fully integrated, the North American market exhibits unique behaviour, and the integration between European and Asian markets is largely based on contractual mechanisms. These studies show that a certain level of integration exists in the global natural gas market, but this integration has not yet been fully realized. In this context, the integration process of the global natural gas market is shaped by factors such as trade dynamics between different regions, price stability and contractual arrangements. Therefore, these elements need to be considered and improved in order to achieve full integration at the global level. Based on literature, integration of global natural gas markets is a complex issue influenced by a variety of factors.

Global Energy Perspective (2023): [27]'s Global Energy Perspective 2023 report models the future outlook for energy commodities, including natural gas, through different scenarios consistent with the Paris Agreement. Natural gas has a variety of applications as a feedstock in electricity generation, heating, industrial processes, and the petrochemical and fertilizer industries. In recent years, there have been fluctuations in global gas prices due to geopolitical events and supply-demand dynamics. The connection between European and Asian gas markets, through liquefied natural gas (LNG), is currently structural, with events occurring in one market influencing global pricing. This structural connection shows that trade flows and price dynamics between regions are interconnected, thanks to the portability and flexibility of natural gas. The important findings in McKinsey's report are as follows:

Natural gas plays an important role in electricity generation due to its low carbon emissions and high efficiency. Natural gas, widely used in residential and commercial areas, is a reliable heating source. In addition, the use of natural gas is common in various industrial production processes such as steel, glass and cement. Petrochemical and Fertilizer Production: Natural gas is used as raw material in the production of petrochemical products and fertilizer. Events such as the Russia-Ukraine conflict have caused supply disruptions and price increases. Supply-Demand Dynamics: Post-pandemic demand increases and disruptions in supply chains have led to price fluctuations. Increase in LNG Trade: The increase in LNG trade between European and Asian markets has caused the prices between these regions to become interconnected. Global Interaction: A supply disruption in Europe or an increase in demand in Asia may also affect prices in other regions.

In this context, McKinsey's 2023 Global Energy Perspective report discusses in detail the future dynamics of natural gas markets and the effects of these dynamics on global energy markets. The versatile use of natural gas and the structural connections between markets play an important role in determining energy strategies and policies.

2.1. Market Integration Research

The concept of market integration in the global natural gas market plays a vital role in understanding the international dynamics of energy supply, demand and pricing. Market integration shows how various regional markets are interconnected and how they respond to changes in supply and demand conditions [28].

[29] examining the period between 2016 and 2022 analysed the integration of American, European and Asian natural gas markets. External shocks and geopolitical tensions, such as the COVID-19

pandemic, have impacted market integration. European and Asian markets experienced reduced integration due to demand and supply shocks. The American market is no longer integrated with the other two markets, which is probably due to the dense and fully utilized LNG infrastructure. Gas price differences adjust asymmetrically to disturbances, indicating different market responses to positive and negative shocks.

2.2. Energy Security And Integration

Integration of global gas markets and creation of the necessary infrastructure can stimulate demand and supply reactions. Larger, more integrated markets protect global energy markets against supply shocks [30]. These statements emphasize the importance of integration of global natural gas markets and infrastructure. Intermarket integration contributes to increasing natural gas demand and meeting supply more effectively. Larger and more integrated markets can reduce the impact of a supply crunch or glut in a single region on global markets, thus providing stability in markets. Therefore, the integration of global gas markets and the creation of the necessary infrastructure are important for global energy security and stability.

International trade in natural gas is divided into three main regional markets: Asia, Europe and North America. [31]; [8] This segmentation occurred due to the limited Liquefied Natural Gas (LNG) transport capacities between the three regions [28] and [2]. Gas pricing mechanisms differ across these markets. In recent years, significant developments such as the shale gas revolution in North America, the rising energy demand in the People's Republic of China, and the conflict in Ukraine have impacted these three markets. These pricing mechanisms, along with specific events in each market, can notably alter the relationship between gas and oil prices. Existing research has not reached a definitive conclusion regarding the connection between oil and natural gas prices [32].

LNG plays a crucial role in market integration due to its delivery flexibility. In contrast, conventional compressed natural gas (CNG) is transported to consumers through pipelines. The direction of pipeline flow and the physical locations of delivery points are fixed, which significantly limits the number of delivery points for CNG and supports regional markets that are not integrated into the international market. The reliance of CNG on pipelines restricts its delivery to specific locations, making it challenging to transport gas flexibly across different regions and ensuring that only the gas needs of the areas along the pipeline route are met. Consequently, the delivery options for CNG are limited, hindering market integration. On the other hand, LNG benefits from a more flexible delivery process since it is liquefied natural gas. Transported by LNG tankers, it is not reliant on pipelines and can access various ports. This flexibility enables LNG to be directed to multiple delivery points. Additionally, because LNG tankers travel by sea, they can be redirected to alternative delivery locations if necessary. This adaptability allows LNG to respond swiftly to changes in demand and reach consumers across a broader geographical area [33].

2.3. North American Market Integration

The market in North America is relatively competitive [8]. In North America, especially the United States, the restructuring of natural gas markets stands out as an important development. Deregulating wellhead prices and providing access to natural gas infrastructure has had a significant impact on shaping market dynamics. The establishment of the Henry Hub in Louisiana as a central trading point facilitated the efficient trading of natural gas. Henry Hub's connectivity to multiple pipelines, LNG infrastructure, and storage facilities has made it a critical hub for natural gas trading. Serving as the delivery and reference point for the NYMEX natural gas futures contract has increased its importance in the market. The availability of natural gas futures and options on NYMEX has provided market participants with the opportunity to manage risk and effectively hedge their positions [2]. The liquid and well-structured state of the natural gas market in Henry Hub has become an important reference point in natural gas trading in North America and has influenced pricing and trading activities throughout the region.

[34], [35], and [36] examined the integration of the North American natural gas market after FERC's 1985 Decision No. 436. This decision enabled the liberalization of the wellhead price of natural gas. In their research, they used correlation and co-integration analyses to detect the existence of integration. On those studies, correlation analysis has been used to measure the strength of a linear relationship between two or more time series. In this context, it was used to determine to what extent natural gas prices move together in various regions of North America. Cointegration analysis is a statistical method that determines whether two or more time series are in a long-term equilibrium relationship. The cointegration of natural gas prices in different regions shows that these prices are affected by the same economic factors and move together in the long

run. These findings provide important evidence supporting the integration of the natural gas market in North America.

[37], [38] and [39] studies have used a variety of econometric tools to confirm the market integration findings of previous studies. The econometric methods used are time-varying coefficients: This technique allows the coefficients of a model to change over time. It can be used to analyse whether the relationship between natural gas prices in different regions has changed over time after FERC's Order 436. They also used Johansen test procedure. This statistical test for co-integration has been used to confirm the findings of previous studies. Impulse-response functions used to measure the dynamic impact of a shock on a system, this technique has been used to analyse how natural gas prices in different regions respond to shocks occurring in another region. These studies confirm the existence of integration in the North American natural gas market by applying advanced econometric analysis and support previous findings.

Another relevant study from the United States is by (Avraam et al., 2020). The extraction of low-cost shale gas from the Marcellus Formation, along with deregulation efforts in both the United States and Mexico, and the growing acceptance of natural gas as a transitional fuel towards a low-carbon economy, have significantly boosted natural gas production in North America. This increase is anticipated to facilitate a rise in LNG exports in the medium term. However, the long-term outlook suggests that a greater reliance on renewable energy sources and deeper electrification will likely suppress both the supply and demand for natural gas.

The lengthy lead times associated with pipeline and field operations underscore the importance of timing for stakeholders in natural gas infrastructure. According to (Avraam et al., 2021), the full integration of the natural gas markets in the U.S., Canada, and Mexico indicates that the mitigation strategies of these three countries are closely interconnected. This study explores the evolution of integrated North American natural gas markets and infrastructure under various assumptions regarding resource availability, technological advancements, and global crude oil prices. The impact of each scenario is assessed using the North American Natural Gas Model. The analysis reveals that, in comparison to trade between the U.S. and Canada, trade between the U.S. and Mexico demonstrates greater resilience to all three shocks. Furthermore, increasing production in Mexico could bolster the domestic Mexican market rather than diminish U.S.-Mexico trade.

2.4. Europe Natural Market Integration

The integration of Europe's natural gas markets underscores why it is important for European countries to come together and form a strong alliance. This integration will enable Europe's energy market to operate more efficiently and increase the security of natural gas supply. In addition, this union will strengthen Europe's hand against major natural gas supplier countries such as Russia and enable it to bargain more effectively on energy prices. This may contribute to Europe becoming more independent in energy supply by reducing its dependence on foreign sources [40]. In this context, according to [41], Russia's attack on Ukraine has plunged the continent into a serious energy crisis due to Europe's over-reliance on Russian natural gas. Using a combination of four globally integrated assessment models, this study explores the differences between Europe's three approaches to living without Russian gas: (a) replacing it with other gas imports, (b) increasing domestic energy production, and (c) reducing demand and improving energy efficiency. It was concluded that buying gas from other trading partners instead of Russian gas could provide consumers with the lowest prices in the short term, but could increase dependence on fossil fuels. While it is stated that investments in renewable energy may be costly and put a strain on consumers, reducing energy demand can provide low-cost energy sector investments and further emission reductions. However, an energy efficiency-focused strategy may also entail the risk of relocating energy-intensive industries, which is an important issue for EU policymakers.

Taking to account of some early studies on European Market Integration shows that there is market cointegration in Europe. For instance, the studies conducted by [42] and [43] are among the first studies examining the cointegration of natural gas import prices in Europe. Cointegration, in this context, means the existence of a long-run equilibrium relationship between these prices. In their research, they presented significant evidence supporting the existence of cointegration, indicating that Europe's natural gas markets had begun the integration process. It ensures the gradual integration of the market or economy into a broader market or global economy through liberalization policies. This process may include steps such as reducing trade and investment restrictions, increasing competition and strengthening market mechanisms.

[42] and [43] believe that market integration in Europe's natural gas sector did not happen suddenly. This process has gradually emerged as various countries in the region implemented reforms to liberalize their natural gas markets. Liberalization often involves deregulation, that is,

allowing more competition and market forces to influence prices. As countries implement these changes, natural gas markets have become increasingly interconnected, laying the groundwork for a more integrated European market. The findings of those researches not only confirmed the existence of cointegration, but also shed light on the ongoing process of market integration in Europe's natural gas sector. Their work has served as a basis for further research in this field.

New studies also confirmed this results. For example [44] aims to determine how natural gas prices in Europe have evolved in various trading centres over the decade (2007-2017) and their level of integration. The study analyses in detail price movements in trading centres located in different regions of Europe. This analysis examines how natural gas prices change over time and how consistent these changes are between different trading centres. In the study, joint stochastic trend analysis was used to test price integration.

The common stochastic trend is a concept that shows whether prices in different markets move together in the long term. If prices follow a common stochastic trend, this indicates the existence of strong integration between markets. Using this methodology, the research evaluated price integration between Europe's major natural gas trading centres.

[44] results reveal a high level of integration between natural gas trading centres in Europe. This finding shows how interconnected markets are and those prices move similarly in different centres. In particular, it has been determined that the Dutch TTF (Title Transfer Facility) hub has assumed the role of reference trading centre in the European gas market. The fact that TTF is a reference centre means that prices in other trading centres are compatible with TTF prices and also [45] shows that natural gas price dynamics in Europe have reached a point where location price differences approach transport tariffs and thus arbitrage is largely saturated. This is considered a sign of a well-functioning pan-European gas wholesale market. The article attempts to understand the evolution of the structure and institutional regulation of the gas industry in Europe, showing that this process is still ongoing and providing general lessons on where European gas markets are heading in the future. Based on this study, it can be said that natural gas price dynamics in Europe show that location price differences are converging to transport tariffs and therefore arbitrage is largely saturated.

Arbitrage reaching saturation point means that price differences are small enough to cover carrying costs and there are no longer large price differences between markets. This indicates that natural gas markets are highly integrated and market efficiency is high and also the fact that arbitrage is limited indicates the existence of a well-functioning pan-European gas wholesale market. This means that markets are interconnected and prices move similarly across Europe. Such a market structure allows trade to occur more easily and transparently, which is beneficial for both producers and consumers.

[45] attempts to understand the evolution of the structure and institutional regulation of the gas industry in Europe. The liberalization of gas markets and the adaptation of regulations have contributed to making markets more competitive and increasing integration. This process is still ongoing and is expected to deepen in the future.

2.5. Asia Natural Market Integration

The Asian natural gas market is dominated by well-established structures, particularly in Japan. LNG prices in Japan are affected by crude oil prices [46]. The future of natural gas in major energy markets such as China, India, Japan and Korea depend on the ability of gas supply to meet demand [47]. While there is evidence of convergence and integration in the natural gas markets of Japan, Korea, Taiwan, and the United Kingdom, the international natural gas market is not fully integrated [26]. The potential for expanded gas trade in Asia and the Middle East is significant. However, this potential requires price reform, improved contractual regulations and private sector participation [48]. Therefore, there are some main point about perspectives on the current status and future of the Asian natural gas market.

Dominant Structures and LNG Prices: The Asian natural gas market is controlled by well-established and powerful structures. Particularly in Japan, LNG (liquefied natural gas) prices are greatly affected by crude oil prices [46]. This means that LNG prices are directly tied to fluctuations in the crude oil market. When crude oil prices rise, LNG prices also rise and vice versa.

Increasing Demand and Supply Capacity: The future of energy markets in major Asian countries such as China, India, Japan and Korea depends on the capacity of natural gas supply to meet the increasing demand in these countries [47]. As industrialization and urbanization increases rapidly in these countries, energy demand increases accordingly. Therefore, whether there is sufficient supply to meet this demand is critical for the sustainability of the natural gas market in the region. [47] addresses the extent to which pipeline gas resources can be provided to complement the existing large-scale LNG imports in Asian markets by 2020 as an important issue. The next decade will be a critical period to determine whether natural gas will become the primary fuel or a secondary energy source in key Asian energy markets such as China, India, Japan and Korea. In order to meet the increasing demand in Asian markets by 2020, large-scale gas supply projects need to be implemented in Russia, Central Asia and the Middle East. The development of pipeline gas resources to complement LNG imports will emerge as an important strategy in the region in the next two decades. On the other hand, Asian markets face commercial challenges in making gas-fired power generation competitive with coal; however, environmental factors can add extra value to gas-fired power generation. The study does not disclose the research methodology.

There is evidence of some convergence and integration between the natural gas markets of countries such as Japan, Korea, Taiwan and the United Kingdom (Li, 2014). However, this integration has not been fully realized. Asian natural gas market is not yet fully integrated. This situation shows that trade and price determination mechanisms between countries are not fully compatible.

The potential for expanded gas trade in Asia and the Middle East is significant. However, some important steps need to be taken to realize this potential (Kubota, 1996). These steps include price reforms, improved contractual regulations and more active participation of the private sector. Price reforms require the creation of pricing mechanisms that are more appropriate and flexible to market dynamics. Contract regulations make trade more transparent and reliable. Participation of the private sector contributes to making the market more competitive and developing innovative solutions.

For example, Qatar recently plays an important role in Asian natural gas market. The country has one of the largest natural gas reserves in the world and is therefore considered a major player in global natural gas supply. Qatar is known for its technological and operational expertise in the natural gas industry and competes effectively in the international natural gas market. In addition, Qatar's development of strategic business partnerships and projects regarding natural gas exports strengthens the country's leadership in this field.

Integration of gas markets refers to the development of interconnected and interdependent gas markets in different regions. This integration is achieved through the following elements. Infrastructure Development, construction of pipelines and LNG facilities supports the development of natural gas trading. These infrastructure investments facilitate the integration of markets by enabling gas to be transported more efficiently [49]. The Liberalization Reforms have led to the emergence of local spot natural gas markets connected via pipelines or LNG routes, thanks to regulatory reforms. These reforms remove barriers between markets and pave the way for free trade. Market Dynamics, spatial arbitrage between these markets appears to play an important role. These dynamics have a significant impact on determining local prices and the formation of a more integrated global gas market [49].

One of the striking works regarding the Asian natural gas market was performed by [50]. Here, the natural gas market after the year 2000 was analysed using the Engle-Granger cointegration and error correction model. The study underlines the regional isolation of global natural gas markets, mainly because of high transportation costs, and identifies three major trading regions: Europe, North America, and Asia. As above-discussed, previous literature has highlighted that the progress of LNG technology and long-term LNG contract pricing mechanism, especially oil-linked pricing, are decisive elements to achieve the integration between markets, especially between Europe and Asia. The present research also supports and further substantiates this fact.

Although the importance of LNG and its pricing in the long term through contracts, few attempts have been made to investigate the role played by a "swing supplier" for market integration. A swing supplier is a supplier who can respond flexibly to changes in market conditions and quickly adapt to changes in demand. Qatar became a critical swing supplier in 2005 and has dominated the global LNG market with more than 30% market share since 2009. Some key results from the study are that: (1) European and Asian markets are integrated; (2) though no direct causality is detected, this research suggests that Qatar's role as a swing supplier may have contributed to the acceleration of these two markets' integration; (3) it also indicates that the North American market was integrated with Europe in the early 2000s, but this linkage has weakened.

In addition, this study maintains that, with pipeline systems dominating North America's natural gas trade, entry into the North American market by a swing supplier is more complex. The study by [50] concludes that the emergence of swing suppliers, along with oil-linked pricing mechanisms, is likely to further integrate the global natural gas market, especially between Europe and Asia. This integration, according to the study, will continue and accelerate in the next couple of years, particularly with the arrival of new swing suppliers like Australia and Russia. These new suppliers are expected to compete with Qatar in promoting more market integration. For instance, Australia has been pursuing large-scale projects for LNG. Its export capacity is seen to increase threefold. In 2020, Australia is seen to have a share of about 17 percent of global LNG capacity, followed by Qatar at an estimated 15 percent. Russia also plans to increase its LNG market share twofold by 2020, with an aim of about 4.5 percent against the 2015 share. The North American market will also be better integrated into the world market if the United States further expands its LNG exports. Projections in this respect vary, but with a wide margin, some believe the United States would emerge as one of the biggest LNG producers, alongside Australia and Qatar.

Table 1: Research examples on market integration

Author(s)	**Countries and Periods Covered**	**Methodology**	**Results**
[26]	North America, Europe, and Asia (January 1997 - May 2011)	Multivariate analysis method	Japan, Korea, Taiwan, and the UK natural gas prices are converging, but North America prices differ and Price integration has been achieved between European and Asian markets.
[51]	USA, UK (2000-2012)	Threshold cointegration analysis	- High integration between US and UK markets between 2000-2008. - There are some obstacles in the 2009-2012 period.
[25]	International	Numerical analysis modeling international energy markets	- Natural gas markets are becoming more globally integrated. - An increase in intercontinental trade is expected with the increase in spot trade and the decrease in LNG costs.
[52]	North America, Europe (1999-2006)	Kalman Filter technique using daily spot prices	- Convergence is observed in spot natural gas prices in the Atlantic Basin. - International LNG trade increases price integration.

[53]	Europe, North America, Asia (after 1992-2001)	Fully modified OLS estimates and causality	- Natural gas prices were closely linked to crude oil prices between 1992 and 2001, but this relationship weakened after 2002. - A global integrated natural gas market has not been formed.
[54]	Around the world (Various periods)	Cointegration analysis, daily price data	- The world oil market is an integrated economic market. - The coal market shows weaker integration. - Natural gas, coal and oil markets are very poorly integrated.
[50]	Europe, Asia, North America (after 2009)	Engle-Granger cointegration analysis, error correction model	- European and Asian natural gas markets have been integrated with the role of "swing supplier" countries such as Qatar and Russia. - The North American market is not integrated with others.
[55]	Asia, Europe (post-Fukushima)	Time-varying regression coefficients, Phillips and Sul convergence test	- A convergence was observed between spot LNG prices and NBP prices after Fukushima. - Competition between LNG markets increases integration.
[56]	Europe, Japan, North America (mid-1990s – 2002)	Principal component analysis, Johansen cointegration procedures	- While the European/Japan and North American natural gas markets show high integration, integration between these two regions has not been achieved.
[57]	East Asia (EAS region, (1999-2010)	Descriptive	- Natural gas markets in the EAS region are either underdeveloped or fragmented. - Harmonization of regulations and technical standards is recommended for the integration of the regional gas market.
[58]	Global (various)	Complex empirical analysis based on spatial balance theory	- Market integration has been discussed theoretically, and variables such as price and trade flows have been examined.
[2]	North America, Europe, Asia (2008)	Kalman Filter technique, regression based on residual fuel oil prices	- Increasing convergence has been observed between North American and European spot natural gas prices. - Integration was evaluated taking into account the impact of residual fuel oil prices.

3. DATA AND METHODOLOGY

In this paper, we use daily closing price of natural gas and liquified natural gas (LNG) indices for future contracts from Thomson Reuters Refinitiv Eikon over 7/29/2014 - 11/01/2023 and of the

Henry Hub, National Balancing Point, JKM, namely, USA, UK, and Japan. Due to different trading hours in different countries the trade information in one market can coincide the market data of a different date.

This section describes the data used in the thesis and the econometric methods employed for analysis.

3.1. Data

Source: Daily closing prices of natural gas and LNG indices for future contracts were obtained from Thomson Reuters Refinitiv Eikon. Sample Period: The data covers the period from July 29th, 2014, to November 1st, 2023. Markets: Three key markets were considered:
USA (Henry Hub - USHH): Represents the natural gas market in the United States. UK (National Balancing Point - UKNBP): Represents the natural gas market in the United Kingdom. (Japan Korea Marker - JPJKM): Represents the LNG market in East Asia.
Data Consideration: Due to differing trading hours across countries, some data points from one market might coincide with another market's data from a different calendar date. Table 2 represents the main index of those countries.

Table 2: Natural Gas and LNG markets

Market	Title	Acronym
JAPAN	Japan Korea Marker	JPJKM
United Kingdom	National Balancing Point	UKNBP
United States of America	Henry Hub	USHH

JPJKM refers to the futures contract for pricing liquefied natural gas (LNG) between Japan and Korea. JPJKM also is an indicator price for natural gas markets in Taiwan and China. Futures contracts are financial instruments that allow parties to purchase or sell an asset at a predetermined price in the future.

3.2. Methodology

The methodology of this study combines different econometric approaches to analyse the integration dynamics of global natural gas markets. The study provides a comprehensive framework for examining both short- and long-term relationships and understanding complex interactions such as volatility spillovers.

In the study, USA (Henry Hub - USHH), UK (National Balancing Point - NBP) and Japan (Japan Korea Marker - JAP) natural gas prices are used as the main variables. The data is obtained at a daily frequency and interpolation techniques are applied to expand the scope of the analysis. For this gaols based on related literature, we caried our several Econometric Methods such as ARDL bound test, Multivariate GARCH (DCC-GARCH and BEKK models).

ARDL Bounds Test: ARDL (Autoregressive Distributed Lag) model was used to detect long-term relationships and short-term dynamics between variables. The ARDL bounds test approach developed by [59] is especially useful in cases where the series have different stationarity levels (I(0) or I(1)). Long-term relationships were examined in the following form:

$$Y_t = \alpha + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{j=0}^{q} \delta_j X_{t-j} + \varepsilon_t \tag{1}$$

Here, ε_t is the error term and the existence of a long-term cointegration relationship within the framework of the ARDL model was evaluated with the bounds test. The null hypothesis states that there is no long-run relationship or short-run dynamic effects between the series. If the null hypothesis is rejected, it is concluded that the parameters are nonzero and there is a significant relationship between the series. In this case, the alternative hypothesis is accepted and the relationship between the series is considered statistically significant.

3.3. Multivariate GARCH

Multivariate GARCH (MGARCH) is a statistical method used to model volatility in financial time series. GARCH models are often used to understand the volatility of financial instruments over time. MGARCH offers a broad perspective by modelling the volatility of multiple financial instruments simultaneously. This model is an effective tool, especially in situations such as dealing with multivariate financial data, portfolio management and risk assessment. It is also useful in evaluating derivative products, such as option pricing, to understand variable effects on the pricing of financial instruments. MGARCH's uses provide a wide range of applications for those who want to understand and manage volatility in financial markets. However, use of the model may vary depending on specific data and analysis requirements. One of the earliest Multivariate GARCH model was introduced by (Bollerslev et al., 1988). It can be written as follows:

$$y_t = \mu_t(\theta) + \varepsilon_t \tag{2}$$

Where $\mu_t(\theta)$ is conditional mean vector and θ is a finite vector and $\varepsilon_t = \sqrt{H_t}$ a positive definite matrix. Later, [60] extent an ARCH (Auto Regressive Conditional Heteroskedasticity) model which allows estimation of time-varying volatility and correlation in a multivariate concept. (R. F. Engle & Kroner, 1995) model allows estimating both diagonal elements (variances) and non-diagonal elements (covariances) of the conditional covariance matrix. Techniques:

$$H_t = CC' + \sum_{j=1}^{q}\sum_{k=1}^{k} A'_{kj}\varepsilon_{t-j}\varepsilon'_{t-j}A_{kj} + \sum_{j=1}^{p}\sum_{k=1}^{k} B'_{kj}H_{t-j}B_{kj} \tag{3}$$

In the first-order BEKK model, the parameter matrices are denoted as C, which are N×N matrices, with C being a lower triangular matrix. The ARCH and GARCH components are constructed using a sandwich product that incorporates a matrix of coefficients surrounding a symmetric matrix. The model is defined as follows:

$$H_t = CC' + A'u_{t-1}u'_{t-1}A + B'H_{t-1}B \tag{4}$$

The expression states that parameter matrices, C, are a lower triangular matrix, and that ARCH and GARCH are formed by a "sandwich product" of coefficients around a symmetric matrix. It also defines the first-order BEKK model. Also, the model expresses a situation considering series situations. Let's say we have two series named A and B. Negative coefficients of A off the diagonal may be less affected when shocks go in the same direction and more when they go in opposite directions. This can make sense in many cases. Likewise, it is possible for A (or less likely B) to have opposite signs in the diagonal elements, but this is rare in practice. For example, if the correlation between two series is close to zero, the A (or B) will have little impact on the transaction series. But in most cases, correlations between series are generally high and positive.

However, in some cases it can be applied to exceptional series such as GARCH models. This can occur when a price's own internal volatility is more dominant than external influences from other prices. For example, in the case of a portfolio, matrices containing the returns of different prices, each prices has its own internal factors, and these factors can act independently of other prices. Therefore, off-diagonal elements can be larger than diagonal elements. Table 7 shows the results of the GARCH-BEKK model.

DCC (Dynamic Conditional Correlation) model is a statistical model used in financial econometrics, especially in modelling volatility structures. This model adapts to changing conditions over time using a dynamic covariance matrix [61]. The main purpose of the DCC model is to model the conditional correlation between asset prices using historical financial data sets. This is extremely important for more accurate assessment and management of risk in financial markets. The model was developed specifically to capture changes in covariance over time, especially when analysing multivariate time series data. In other words, that correlations can change over time. This method is used to predict future correlations based on past correlations [62].

Multivariate GARCH models allow estimating conditional covariances between asset returns; Explicitly modelling this interaction, however, could improve the accuracy of volatility estimates for a portfolio that includes these components [63]. In traditional financial modelling especially in The Constant Expected Returns Model approaches, it is common to assume that an asset's return over time is normally distributed with a constant mean and constant variance[1]. However, the DCC model recognizes that these correlations may change over time due to market conditions, economic events, or other external factors. By adding a dynamic covariance matrix, the DCC model allows a more realistic modelling of the relationships that develop between different financial instruments.

In practice, the DCC model can be used to estimate time-varying conditional correlations between assets. This information is valuable for risk management, portfolio optimization and other financial decision-making processes. By taking dynamic correlations into account, financial analysts and investors can make more informed decisions about the potential risks associated with different

[1] https://didattica.unibocconi.it/mypage/dwload.php?nomefile=ch4_120140212101757.pdf

assets and adjust their strategies accordingly. The DCC model was proposed by Robert Engle in 2002 and aims to address a larger set of variables than more fully parameterized models that add two scalar parameters that drive a "GARCH(1,1)" model over the covariance matrix as a whole [64], [65]. DCC was developed to capture how the correlation between variables in multivariate time series data changes over time. Correlations in financial data are generally considered to be constant, but in practice correlations can change over time. Particularly during periods such as financial crises, economic fluctuations or other extraordinary events, correlations between financial assets can change significantly.

Based on [62], R_t is taken as follows:

$$R_t = diag(q_{11,t}^{\frac{1}{-2}} \dots q_{NN,t}^{\frac{1}{-2}})\, Q_t\, diag(q_{11,t}^{\frac{1}{-2}} \dots q_{NN,t}^{\frac{1}{-2}}) \tag{5}$$

where;

$$Q_t = (1 - \alpha - \beta)\overline{Q} + \alpha u_{t-1}u'_{t-1} + \beta Q_{t-1}$$

According to [66], if we have positive definite Q_t , it implies R_t to have positive sign and $\overline{Q}$ is an $N \times N$ unconditional variance matrix of u_t .

$$\rho_{12,t} = \frac{(1-\alpha-\beta)\overline{q_{12}} + \alpha u_{1,t-1}u_{2,t-1} + \beta q_{12,t-1}}{\sqrt{(1-\alpha-\beta)\overline{q_{11}} + \alpha u_{1,t-1}^2 + \beta q_{11,t-1})(\,(1-\alpha-\beta)\overline{q_{22}} + \alpha u_{2,t-1}^2 + \beta q_{22,t-1})}} \tag{6}$$

(11)

ρ values represent correlation coefficients, while α and β coefficients represent variance model parameters and $\alpha \geq 0$ and $\beta \geq 0$ and $\alpha + \beta < 1$.

The results of DCC model are shown in Table.

For applying our methodology, we use also unit root test establishes whether or not prices series for each of the market is stationary, which is an assumption that many time series models require. Unconditional Correlation analysis examines the degree of relationship between the price series of the various markets taking a coefficient of 1 while excluding the dependence on time.

DCC (Dynamic Conditional Correlation) Model: This model incorporates the temporal component into the most basic form of correlations between the price series, such that the co Relative Layouts may change over time. By applying these methods, the thesis aims to investigate the following: Necessary conditions include stationarity of price series of every market. The degree of co-integration of the markets – that is, the extent of direct dependence between the markets. Fluctuating nature of risks and co-movement between markets across time. The advantage of this approach is that it produces simultaneous views of both the natural gas and the LNG market dynamics in the USA, UK, and Japan, thus giving a more holistic view of the markets in question.

4. EMPIRICAL FINDINGS

Our analysis that is based on unit root tests, analysis of the unconditional correlation's nature, ARDL bound test, and the application of multivariate GARCH models with GARCH-BEKK or DCC models will help to focus on several main questions in the natural gas and LNG markets. Thus, using the augmented Dickey-Fuller test, we will be able to identify if or not the price series of each market are stationary, which is a necessary step for further analysis. An unconditional correlation analysis will identify the basic level of linear dependency between the markets. Additionally, the multivariate GARCH structure will go a notch higher by modelling not only the volatility but also the time varying aspect of the correlation. This will enable us to see the relationships that exist between the variability of a certain market and variability of other markets as captured by the GARCH BEKK model and to see the changes in the correlation among the markets over time by the DCC model. These insights will make it possible to understand relationships and risks within the network of entities related to the global natural gas and LNG market.

When we look at JPJKM's market prices between 2014-2023, we see they started above $10 in 2014, but by the beginning of 2015 they fell below $10 and maintained this level until the end of 2017. Although they tried to rise above $10 during 2018, they continued to remain below $10 in 2019 and 2020. However, it showed an upward trend after 2020 and rose to 69.95 dollars in August 2022. It then experienced a decline again and fell to $10 in the July 2023, and started trading around $18 in the October 2023.

These price movements appear to be shaped by the interaction of various factors in the market. In particular, factors such as energy demand, global economic situation, especially geopolitical events and energy supply-demand balance appear to affect Japan's market price.

The rise seen especially after 2020 may possibly be due to changes in the energy market or increase in demand, and later Russia Ukraine conflict in 2022. However, the fact that the level around 18 dollars continues through the October 2023 and maintains a more stable stance compared to the fluctuations in previous years can be interpreted as the dynamics in the market stabilizing or settling at a certain level.

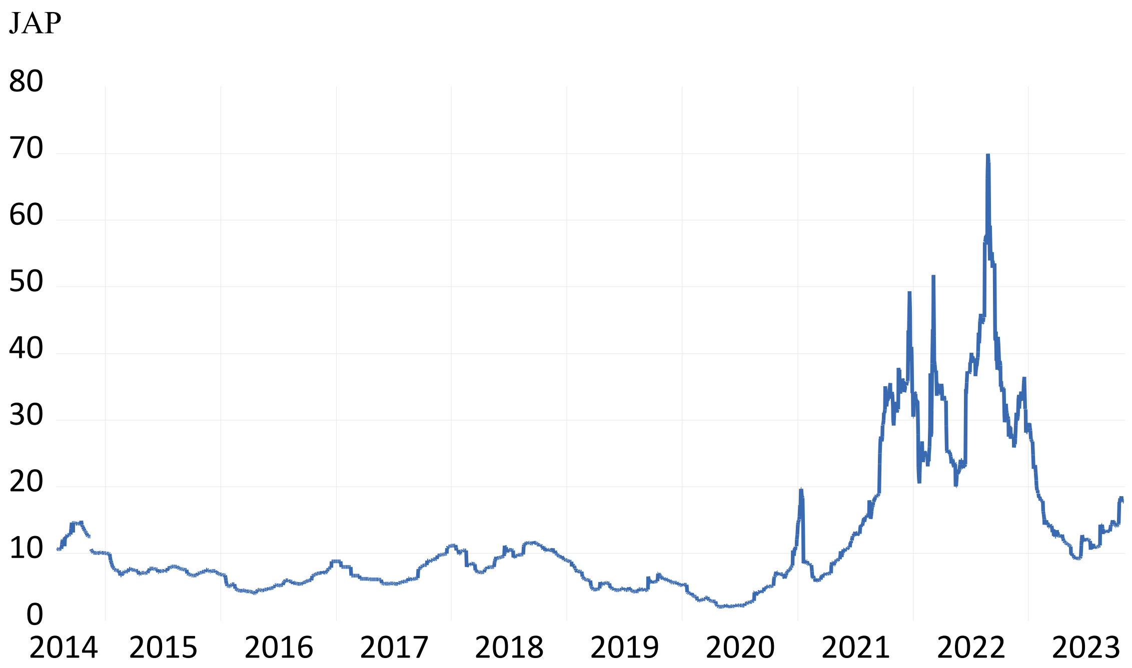


Figure 1: Market prices, JKM

In case of NBP, in early 2014, NBP was around $10. However, between 2015 and late 2017, this price dropped to $7. It reached $10 again in the 9th month of 2018, but decreased again until the 5th month of 2020 and fell to around $1. Due to the impact of the Russia-Ukraine war, prices began to increase and reached 75 dollars (maximum value) in the 8th month of 2022. However, it then started falling below $10 again in the 6th month of 2023.

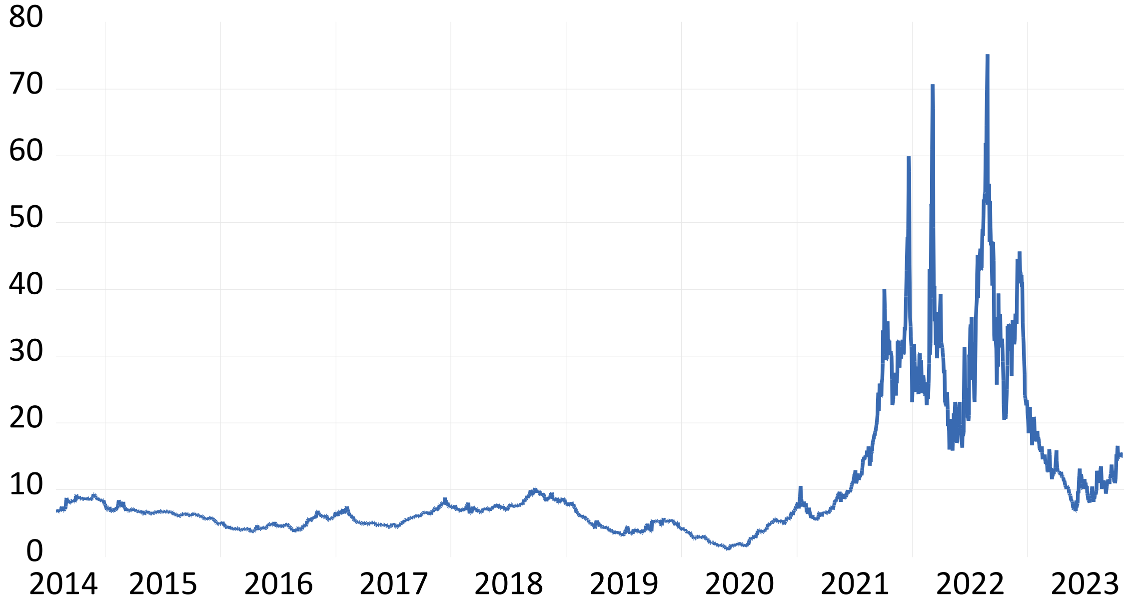


Figure 2: Market prices, NBP

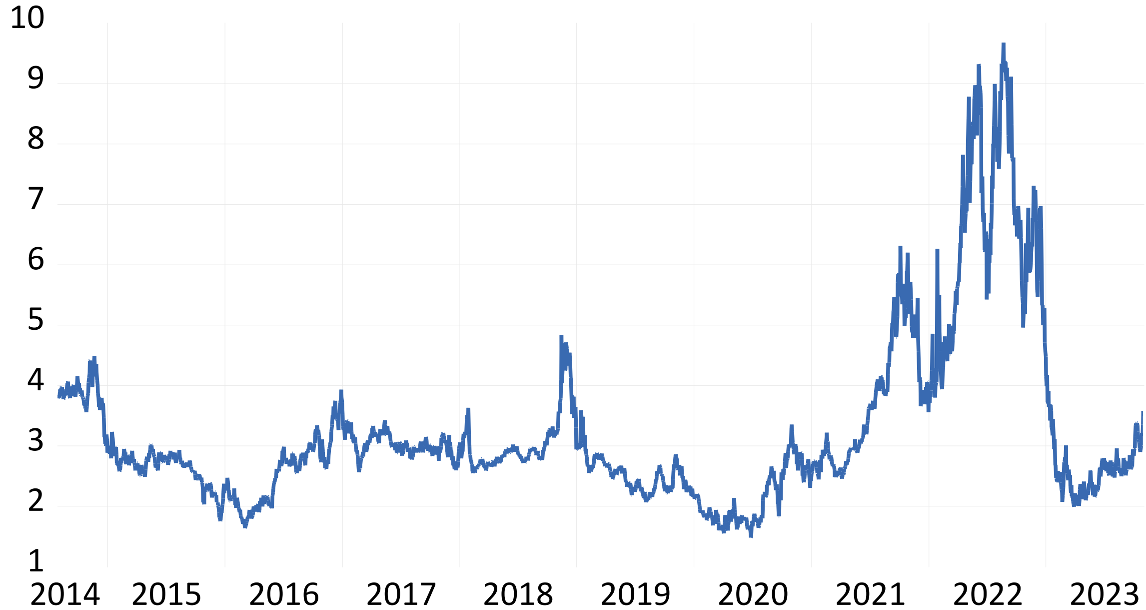


Figure 3: Market prices, USHH

Figure 3 shows the price series of USHH started at $3.8 in the seventh month of 2014, until it dropped as low as $1.9 at the beginning of the sixth month of 2016. There was then a continued decline throughout 2016, and this trend continued until the end of 2018. Following an increase that continued until the end of 2018, there was a decline in the period until mid-2020. After that, a rise occurred, reaching $6.97 by the end of 2020, but then a decline occurred again.

4.1. Descriptive Statistics

Table 3 summarizes descriptive, stationarity, heteroscedasticity, and normality of the series. It contains the statistical summary of three different variables: JAPJKM, UKNBP and USHH. Looking at the average values, the mean of the JAP variable is the highest, while NBP and USHH have lower values on average, respectively. When examined, median values show the central tendency of each variable; Among the medians, JAP has the highest value and USHH has the lowest value. Looking at the minimum values, the highest value in JAP was 1.995, while the lowest value in NBP was 1.027. Standard deviation values indicate that JAP and NBP have a wide range of data, while USHH has a lower variability. While skewness and kurtosis values indicate the distribution characteristics of all three variables, the Jarque-Bera test evaluates the suitability of the data for normal distribution. In the overall, considering the statistical properties of each variable, it can be seen that JAP, NBP and USHH have different distribution characteristics.

Table 3: Summary statistics of series

	JAP	NBP	USHH
Mean	11.763	10.332	3.241
Median	7.950	6.756	2.823
Maximum	69.955	75.223	9.680
Minimum	1.995	1.027	1.482
Std. Dev.	10.215	10.053	1.424
Skewness	2.160	2.472	2.186
Kurtosis	7.790	9.656	7.955
Jarque-Bera	4190.60	6921.98	4396.729
Probability	0.0000	0.0000	0.0000

4.2. Unit Root Test

Unit root test is a statistical test that checks whether a time series is stationary or has a unit root. Presence of Unit root means that the variable follows a random walk process, making the variable unpredictable and unstable. A nonstationary variable has a mean, variance, or autocorrelation that changes over time, violating the assumptions of many statistical methods. Therefore, it is important to test for unit roots before applying any analysis to a time series variable.

Augmented Dickey-Fuller (ADF) introduced by [67] and Phillips-Perron (PP) unit root tests introduced by [68] were applied to determine the integration level of the series. The results of the unit root tests are presented in table 4.

Table 4: Unit root test results

variables	ADF	PP	result	ARCH effect
JAP	-2.2234	-2.1760	I(1)	$\varepsilon_{-1}^2 = 0.195^{***}$ There is ARCH effect
ΔJAP	-50.60***	-50.60***		
NBP	-3.778**	-3.083**	I(0)	$\varepsilon_{-1}^2 = 0.287^{***}$ There is ARCH effect
USHH	-2.6968	-2.4727	I(1)	$\varepsilon_{-1}^2 = 0.303^{***}$ There is ARCH effect
ΔUSHH	-55.05***	-55.36***		

Not: The signs ** and *** represent; 5%, 1% significance level, respectively.

Unit root test results show that the ADF and PP tests for the JAP series contain unit roots and therefore the series is not stationary. However, the ADF and PP results obtained after taking the first difference of the series show that the series is I(1) stationary within the 99% confidence interval. This shows that the JAP series, which initially contained a unit root, became stationary after the first differencing process. ADF and PP test results for the NBP series show that the series is stationary at the I(0) level within the 95% confidence interval. The USHH series, like the JAP series, has become stationary after the first difference and its integration level is I(1).

The ARCH (Autoregressive Conditional Heteroskedasticity) effect is a condition that indicates that volatility (variability) in financial or economic time series varies over time in econometric models. This effect is frequently observed, especially in the examination of variables such as stock returns, exchange rates or interest rates in financial markets. The ARCH effect shows that the variance of the error terms (residuals) in the series is not constant, but rather changes as a function of the squares of past error terms.

Engle's ARCH test is usually used to detect the ARCH effect. The test checks whether there is autocorrelation in the variance of the error terms of a series. If the ARCH effect is present, this violates the assumptions of standard regression analysis (especially the assumption of constant variance - homoskedasticity), which can reduce the reliability of the results.

Null hypothesis (H0): There is no ARCH effect in the error terms (homoscedasticity, constant variance assumption is valid).

Alternative hypothesis (H1): There is an ARCH effect in the error terms (variance depends on the squares of past error terms).

Based on Heteroskedasticity Test results $\varepsilon_{-1}^{2} = 0.195$ (Prob. = 0.000) (coefficient of the square of the previous error term). This coefficient is also statistically significant and being positive and significant shows that the variance changes over time and depends on past error squares that H0 is rejected. This shows that the ARCH effect exists. The same situation are valued for NBP and USHH. There fore there are ARCH effect in all three variables.
According to these test results, there is an ARCH effect in the error terms. In other words, the variance is not constant but is related to the squares of past error terms. Since the existence of the ARCH effect violates the assumption of homoscedasticity in standard regression analysis, special methods such as ARCH or GARCH models should be used in this type of time series analysis. These models allow for more accurate estimates by taking into account the variable variance.

4.3. Unconditional Correlation Analysis.

Unconditional correlation analysis is a type of analysis that examines the relationship between two or more variables. This analysis does not take into account the factors or conditions that determine the relationship; that is, no conditions are imposed on the correlation values. This method is used to evaluate the overall relationship between variables and is used to measure relationships from a general perspective, not for the purpose of understanding how the correlation may change under specific conditions. Unconditional correlation analysis is frequently used by researchers who want to understand and measure the overall correlation between variables. Table 5 shows the results of Unconditional correlation.

Table 5: Unconditional correlation results

Variable	USHH	NBP	JAP
USHH	1	0.8073 (0.000)	0.843 (0.000)
NBP	-	1	0.967 (0.000)
JAP	-	-	1

Note: Numbers in parentheses show the Probability.

Correlation coefficients between USHH, NBP and JAP variables and their probability values are added to the table. Correlation coefficients show the relationship between variables, and probability values indicate whether this relationship is statistically significant. The values in the table show that the correlation between USHH and NBP is 0.807346, the correlation between USHH and JAP is 0.843593, and the correlation between NBP and JAP is 0.967890. In addition to these values, the probability values calculated for each correlation are also given. Based on table 5, there are a strong correlation among the variables, especially between NBP and JAP.

The evaluations made above explain the relationships between variables. However, correlation coefficients only measure linear relationships and may not adequately capture other types of relationships (e.g., nonlinear relationships). Therefore, other analysis methods and factors should also be taken into account in order to fully understand and interpret the relationships. Table shows the results of the cointegration analysis. For long run relationship among the variables we use ARDL developed by [69].

Table 6: ARDL bound test results

	ARDL ((5,1,0)
NBP	0.052 (0.610)
JAP	0.055

	(0.658)
C	2.034 (6.46)
EC_{t-1}	-0.016[2] (-3.731)***
F-Bounds	3.875** (upper bound of %5 significance is 3.87)
χ^2_{Serial}	1.53 (Prob.> 0.05)
CUSUM	Stable
CUSUMSQ	Not stable

Not: The signs ** and *** represent; 5%, 1% significance level, respectively.

ARDL bound test results shows the results of the cointegration analysis. ARDL model (developed by [69] was used for the long-term relationship between variables. According to the ARDL model results, there appears to be a long-term relationship between USHH, NBP and JAP variables. Additionally, it turns out that the NBP and JAP have positive impact on USHH. According to the test results, the F-Bounds value, is bigger than upper bound of %5 significant (3.87) and also coefficient of error correction term (EC_{t-1}) is negative and within the accepted range which indicates that there is a long run relationship between selected variables. Moreover, the results of CUSUM and CUSUMSQ show that the model is stable but CUSUMSQ is unstable. Based on χ^2_{Serial} , there is no autocorrelation in the model. These findings support the long-term relationship and variables are cointegrated. The results of BEKK-GARCH model is summarised as follows:

Table 7: BEKK-GARCH(1,1) Model results

Parameters	Coefficient	t-Stat	t-statistics
μ_{JAP}	-0.0242	-4.0448	0.00005
μ_{USHH}	0.0005	0.296	0.7671
μ_{NBP}	6.338	258.993	0.00000
C(1,1)	0.1190	27.71	0.00000
C(2,1)	0.00121	0.782	0.4336
C(2,2)	-0.0075	-7.190	0.0000

[2] EC = USHH - (0.052NBP + 0.055JAP + 2.0343)

C(3,1)	-0.0309	-2.60	0.00932
C(3,2)	-0.0098	-0.293	0.76942
C(3,3)	0.0000	1.692 e-04	0.9998
A(1,1)	0.4291	14.951	0.0000
A(1,2)	-0.0114	-4.557	0.00000
A(1,3)	0.2237	3.053	0.00226
A(2,1)	-0.1670	-3.948	0.00007
A(2,2)	0.2223	21.16	0.00000
A(2,3)	-0.2686	-1.689	0.0911
A(3,1)	0.0302	16.720	0.0000
A(3,2)	0.0015	4.015	0.00005
A(3,3)	0.6675	24.25	0.0000
B(1,1)	0.7492	46.632	0.0000
B(1,2)	0.0061	2.835	0.0045
B(1,3)	0.3866	3.281	0.0010
B(2,1)	-0.0557	-1.8886	0.05894
B(2,2)	0.96983	445.293	0.00000
B(2,3)	-0.3363	-1.219	0.2227
B(3,1)	0.0223	6.720	0.00000
B(3,2)	-0.0004	-0.549	0.58263
B(3,3)	-0.7677	-36.564	0.00000

Note: first differences of nonstationary variables (USHH and JAP) is used.

The results from the BEKK estimation reveal that most pairs in the analysis are statistically significant. Specifically, the diagonal elements of the matrix A(i,i) primarily stem from lagged shocks within each market's conditional variance, while the off-diagonal elements in matrix A capture the influence of past innovations from other markets. For instance, the coefficient A(1,3) is statistically significant at the 1% level, with a value of 0.223, indicating that past shocks from the Japanese market (JAP) have a transmission effect to the National Balancing Point (NBP) market. Conversely, the A(3,1) coefficient reflects this transmission in the reverse direction, with a statistically significant value of 0.030, showing that shocks from NBP have an impact on JAP.

Further analysis shows that the A(1,2) coefficient, which equals -0.011 and is statistically significant at the 1% level, highlights the transmission of past shocks from JAP to the U.S. Henry Hub (USHH) market. On the other hand, the coefficient A(2,1) is -0.167 and statistically significant, demonstrating a dual persistence ARCH effect between JAP and USHH. The coefficient A(2,3) is -0.268 but is not statistically significant at the 5% level, suggesting that past shocks do not transmit from USHH to NBP. However, the A(3,2) coefficient is 0.001 and statistically significant at 1%, indicating a transmission of shocks from NBP to USHH, which establishes a one-way effect from NBP to USHH.

In addition, the A(3,1) coefficient remains statistically significant at 0.030, indicating the persistence of an ARCH effect from NBP to JAP. This suggests that shocks originating from NBP to JAP create a lasting impact. Meanwhile, the A(1,3) coefficient also remains significant, implying that shocks from JAP influence NBP as well. Thus, cross-market shocks are transmitted between all three markets, forming bilateral linkages. However, the relationship between USHH and NBP is unidirectional, as cross-shocks from USHH do not affect NBP.

The GARCH parameters B(i,i) offer insight into how volatility in one market responds to the historical volatility in the other markets, revealing spillover effects. The coefficients B(1,2) and B(1,3), valued at 0.006 and 0.38 respectively, are statistically significant at the 1% level, indicating that the volatility from JAP influences the other two markets. In contrast, the coefficients B(2,1) and B(2,3) are -0.055 and -0.336, but neither is statistically significant at the 5% level, suggesting there is no significant spillover effect from USHH to the other markets.

For NBP, the coefficient B(3,1) is 0.022 and statistically significant at the 1% level, implying a spillover effect from NBP to JAP. However, the spillover is one-sided, as the B(3,2) coefficient is not statistically significant, indicating no significant spillover from NBP to USHH.

4.5. DCC (Dynamic Conditional Correlation)

As emphasized in the Methodology section, understanding the dynamic nature of relationships between assets in financial markets is crucial for effective risk management and portfolio optimization. In this context, the Dynamic Conditional Correlation (DCC) model developed by Robert Engle provides a powerful tool for analysing and modelling time-varying correlations between asset returns. The DCC model aims to accurately capture changes in correlations, even in extraordinary circumstances such as financial crises, economic fluctuations or external shocks.

Thus, it provides a more realistic and applicable perspective for investors and analysts compared to traditional fixed correlation assumptions. The results are summarised in following table.

Table 8: DCC GARCH report

	DCC	
	Coefficient	t-statistic
ρ_{21}	0.0219	0.673
ρ_{31}	-0.0013	-0.0299
ρ_{32}	0.0182	0.597
α	0.0176**	2.053
β	0.95262***	33.24

Information Criteria (to be minimized):

Akaike	3.382759
Shibata	3.382661
Schwarz	3.423499
Hannan-Quinn	3.397575

Individual Normality Tests

Series: DJAP_INTERPO

	Statistic	t-Test	P-Value
Skewness	2.9577	59.388	0.00000
Excess Kurtosis	65.780	660.67	0.00000
Jarque-Bera	4.3911e+005	.NaN	0.00000

Series: DUSHH

	Statistic	t-Test	P-Value
Skewness	0.55326	11.109	1.1360e-028
Excess Kurtosis	3.0789	30.923	5.8488e-210
Jarque-Bera	1077.5	.NaN	1.0474e-234

Series: NBP

	Statistic	t-Test	P-Value
Skewness	-0.16967	3.4068	0.00065723
Excess Kurtosis	-1.4378	14.441	2.8508e-047
Jarque-Bera	219.71	.NaN	1.9541e-048

Q-Statistics on Squared Standardized Residuals

Series: DJAP_INTERPO
Q(5) = 0.0868764 [0.9998853]
Q(10) = 0.516409 [0.9999923]
Q(20) = 2.01431 [0.9999999]
Q(50) = 43.9474 [0.7136716]

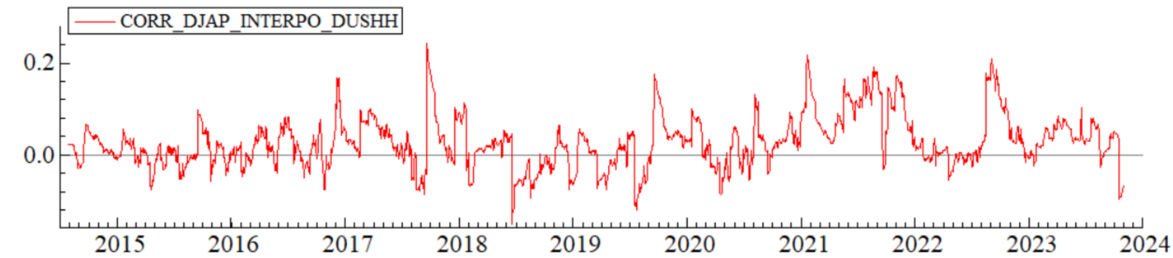
Series: DUSHH
Q(5) = 3.21320 [0.6671544]
Q(10) = 7.47956 [0.6795269]
Q(20) = 16.2010 [0.7040760]
Q(50) = 37.1875 [0.9102680]

Series: NBP
Q(5) = 48.4776 [0.0000000]
Q(10) = 50.8010 [0.0000002]
Q(20) = 90.7712 [0.0000000]
Q(50) = 310.754 [0.0000000]

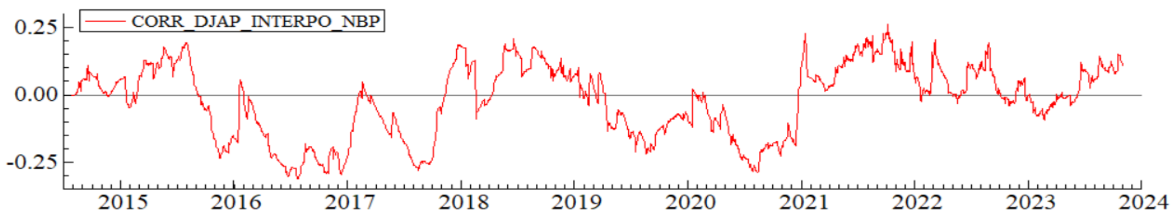
H0 : No serial correlation ==> Accept H0 when prob. is High

Based on table 8, the estimation results of the DCC- EGARCH model show that the parameters $\alpha \geq 0$ and $\beta \geq 0$ (non-negative) and the condition of $(\alpha + \beta) = 0.01769 + 0.9526 = 0.97029 < 1$. In additional α has an estimated value of 0.0176 with a standard error of 0.0086, resulting in a t-value of 2.053 and a p-value of 0.0402 and β has a high t-value (33.24) and a very low p-value (0.0000), indicating high statistically significance. The series passed various normality tests for DJAP_INTERPO, DUSHH and NBP. Q-statistics on series of standardized residuals and tests on squared standardized residuals indicate the absence of serial correlations on a series-by-series basis. These results indicate that the model is generally well-fitted.

JAP-USHH



JAP-NBP



USHH-NBP

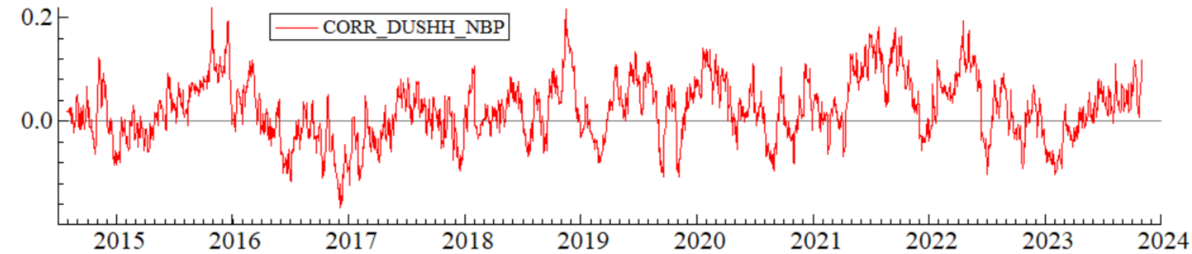


Figure 4: DCC among variables

The results show that there are strong reactions between the DJAP and NBP markets, both to their own past shocks and to the other market's past shocks. We can also observe this situation in the graphs. The correlation coefficient between JAP and NBP remains high over time, and shocks in both markets appear to affect the other market.

The US market is less affected than the other two markets. Estimation results also support this situation. Shocks in the United States do not significantly affect the other two markets, and historical volatility in the United States does not affect volatility in the other two markets. We can see this situation in the graph. The correlation coefficient between the USA and other markets remains lower over time and the effect of the USA on other markets remains limited.

4.6. Model Robustness Under Economic Policy Uncertainty

The Dynamic Conditional Correlation (DCC) model is employed in this study to analyse the evolving correlations between the US, UK (NBP), and Japan (JKM) natural gas markets over time. Recognizing the importance of macroeconomic factors in shaping market dynamics, the Global Economic Policy Uncertainty (EPU) Index has been incorporated into the analysis to examine its potential impact on market interconnectedness and volatility. The EPU Index serves as a proxy for global economic uncertainty, capturing changes in investor sentiment and policy-induced risks, which are known to influence energy markets and cross-border capital flows.

By integrating the EPU Index into the DCC model, this study aims to assess how periods of heightened economic uncertainty affect the correlations among the three major natural gas markets. The inclusion of this variable provides a broader perspective on the underlying drivers of market linkages and offers valuable insights into how external macroeconomic factors contribute to volatility transmission and interdependence. The extended analysis is expected to enhance the understanding of market behaviours during periods of global economic stress and stability.

Table 9: Unit root test results

variables	ADF	PP	result	ARCH effect
JAP	-2.2234	-2.1760	I(1)	$\varepsilon^2_{-1} = 0.195$*** There is ARCH effect
ΔJAP	-50.60***	-50.60***		
NBP	-3.778**	-3.083**	I(0)	$\varepsilon^2_{-1} = 0.287$*** There is ARCH effect
USHH	-2.6968	-2.4727	I(1)	$\varepsilon^2_{-1} = 0.303$*** There is ARCH effect
ΔUSHH	-55.05***	-55.36***		
GEP	-2.65*	-3.083**	I(0)	-

Note: The signs ** and *** represent; 5%, 1% significance level, respectively.

Unit root test results show that the ADF and PP tests for the JAP series contain unit roots and therefore the series is not stationary. However, the ADF and PP results obtained after taking the first difference of the series show that the series is I(1) stationary within the 99% confidence interval. This shows that the JAP series, which initially contained a unit root, became stationary after the first differencing process. ADF and PP test results for the NBP series show that the series is stationary at the I(0) level within the 95% confidence interval. The USHH series, like the JAP series, has become stationary after the first difference and its integration level is I(1). The Global Economic Policy Uncertainty Index also is stationary at the I(0).

The findings from the DCC model, augmented with the EPU Index, will contribute to a more comprehensive discussion of the interconnectedness of natural gas markets. This approach underscores the dynamic nature of market relationships, emphasizing the role of global uncertainties in shaping the strength and direction of correlations between markets.

Table 10: DCC model results

	DCC	
	Coefficient	t-statistic
ρ_{21}	0.223*	1.72
ρ_{31}	0.069	0.581
ρ_{41}	0.181**	1.94
ρ_{32}	0.158*	1.715
ρ_{42}	0.020*	1.82
ρ_{43}	0.189*	1.81
α	0.204***	3.310
β	0.404**	2.041

The results of the DCC model satisfy the necessary conditions for model stability and validity and figure 5 shows the results of the DCC relationship of series.

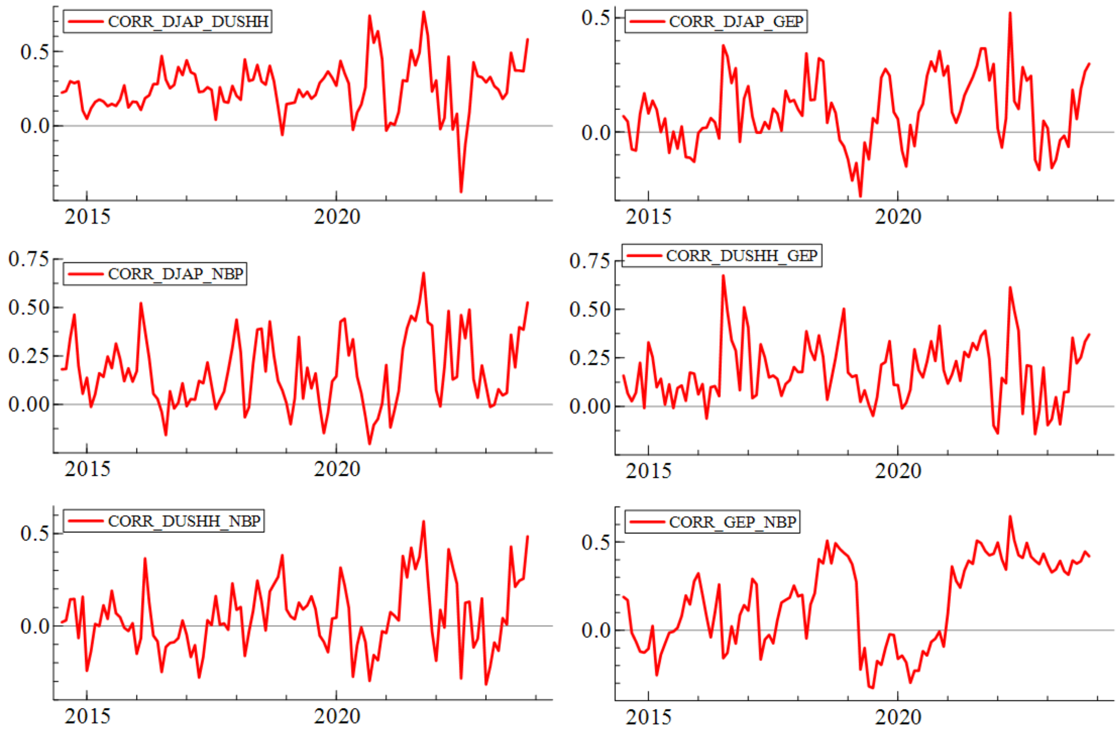


Figure 5: DCC subplots

The six subplots represent the dynamic conditional correlations (DCCs) between pairs of natural gas markets over time. (CORR_JPJKM_USHH) represents the correlation between Japan Korea Marker (JPJKM) and Henry Hub (USHH). The correlations are relatively low, hovering around -0.5 to 0.6, with some fluctuations over time. The relationship strengthens slightly during specific periods, especially around 2020–2021, possibly due to global market shocks affecting both regions. Overall, the JPJKM and USHH markets exhibit a weak-to-moderate interconnection. (CORR_JPJKM_GEP) shows the correlation between JPJKM and the Global Economic Policy Uncertainty Index (GEP). The correlation is relatively low-moderate, mostly between -0.3 and 0.5, but increases marginally post-2020, likely reflecting heightened sensitivity to global policy changes during this period. This suggests a limited but emerging connection between Japan's natural gas prices and global policy uncertainty.

(CORR_USHH_GEP) subplot illustrates the correlation between USHH and GEP. The correlation is moderate and strong, fluctuating ranging from -0.1 to 0.7. USHH appears to be relatively affected from global policy uncertainty, especially in brief periods of slightly higher correlation. (CORR_JPJKM_UKNBP) represents the correlation between JPJKM and National

Balancing Point (UKNBP). The correlations are moderate to strong, ranging from -0.2 to as high as 0.7 in certain periods, particularly after 2020. This indicates a significant degree of integration between Japan and UK natural gas markets, potentially due to shared global factors or regional interdependence.

(CORR_USHH_UKNBP) shows the correlation between USHH and UKNBP. The relationship is weak-moderate, mostly ranging from -0.3 to 0.5, with occasional spikes around 0.3. The weak-moderate correlation suggests that the U.S. market was moderate affected by the UK natural gas market. (CORR_UKNBP_GEP) illustrates the correlation between UKNBP and GEP. The correlations are moderate, generally between -0.3 and 0.5, and increase post-2020, suggesting growing sensitivity of UK natural gas prices to global policy uncertainty. This indicates that the UK market is more affected by global economic conditions compared to the U.S. market.

The graphs demonstrate a moderate-to-strong relationship between the Global Economic Policy Uncertainty Index (GEP) and other variables, particularly Japan Korea Marker (JPJKM), National Balancing Point (UKNBP), and Henry Hub (USHH) after 2020. This trend reflects the growing influence of global economic policy uncertainty on natural gas markets. The correlation values often range from 0.3 to 0.7, suggesting a substantial degree of co-movement between GEP and these energy markets.

One potential explanation for this relationship is the heightened global economic volatility following major geopolitical and economic events, such as the COVID-19 pandemic, disruptions in supply chains, and the Russia-Ukraine conflict. These events likely amplified uncertainty in global policy-making, directly affecting energy demand, trade, and pricing. Natural gas markets, being crucial to energy security, are particularly sensitive to shifts in global policies, such as sanctions, tariffs, or environmental regulations, which impact supply and pricing mechanisms. Additionally, the increasing integration of energy markets with global financial systems could explain this stronger relationship. Policy uncertainty influences exchange rates, inflation expectations, and investor sentiment, which in turn affect energy prices. For instance, rising policy uncertainty often leads to higher energy price volatility as investors adjust their risk assessments and hedging strategies. The moderate-to-strong relationship between GEP and natural gas markets underscores the growing role of global economic and political developments in shaping energy market dynamics. This trend reflects the interconnectedness of policy decisions and energy market responses, particularly during periods of heightened global uncertainty.

The DCC-EGARCH model managed to accurately model the complex relationship between three natural gas markets. Forecast results and graphs clearly reveal how strong the connections between markets are and how shocks in each market affect other markets. These findings provide important implications for risk management and investment strategies in natural gas markets.
The similarities and differences between the results of the study and the findings in the literature can be summarized as follows:

There are findings in the literature (e.g., R. Li et al., 2014b; Nick & Tischler, 2014) that European and Asian natural gas markets provide price integration and establish long-term relationships. In our study, a long-term relationship was found between the ARDL model and USHH, NBP and JAP variables. This situation is consistent with the literature.

The BEKK model results in our study show that there is a two-way shock transmission between Japan and NBP and a one-way effect from NBP to USHH. This is consistent with the integration and shock transmission findings between natural gas prices in studies such as (Neumann, 2009) and (Mu & Ye, 2018).

Our study found that there was a volatility spill over from NBP to Japan and that Japan spread volatility to other markets. This situation is consistent with the findings that LNG trade and regional price movements increase integration, as emphasized in the studies of [25] and [52].
Our study's conclusion that the US market (USHH) is less affected than other markets and moves with its own internal dynamics is parallel to the findings in the literature (e.g., Bachmeier & Griffin, 2006; S.-H. Kim et al., 2020c). While the literature (e.g., Nick & Tischler, 2014) reported high integration between the US and UK natural gas markets, especially in the period 2000-2008, our study indicated that the effects from USHH to NBP were weak and had a one-way relationship. This difference may be due to the differences in the periods used and changes in market dynamics. While our study emphasized that there was a strong and reciprocal relationship between Japan and NBP, the (L'Hégaret & Hirschhausen, 2003) study indicated that the integration between these

two regions was limited. This difference can be explained by changes in market conditions such as the post-Fukushima period (Mu & Ye, 2018).

5. CONCLUSION

This study examines the level of integration in global natural gas markets, revealing how different regional markets interact and their interdependence. The effects of elements such as geopolitical factors, infrastructure, regulatory frameworks and market dynamics on market integration have been evaluated.

BEKK model results analysed in detail the shock transmission and spillover effects between the three major natural gas markets: USA, NBP (UK) and Japan. The findings of this model showed strong reactions between Japan and NBP markets to both their own past shocks and the other market's shocks. Japan's historical conditional volatility spills over significantly to the NBP and US markets, but shocks from the US do not show significant spillover effects to other markets. NBP also has a spillover effect towards Japan, but this relationship is one-sided and the US market plays a less important role in these interactions.

The DCC model results are consistent with the BEKK model findings and examined correlations between markets in more detail. It has been observed that the correlation between DJAP and NBP remains high over time and shocks between these two markets affect each other. The US market is more isolated than the other two markets, and shocks in the US do not significantly affect other markets. This demonstrates the independence of the United States in the natural gas market and its lower interconnectedness compared to the other two markets.

Overall, the findings obtained using the BEKK and DCC models make a significant contribution to understanding the dynamics of global natural gas markets and the interactions between these markets. Strong connections between Japan and NBP explain how regional shocks and volatility spillover occur, providing important information for market participants to consider in risk management and investment strategies. The fact that the US market is less affected than others shows that the US maintains the strength and independence of its domestic market.

In conclusion, this study provides a valuable framework for understanding the degree of integration and market dynamics in global natural gas markets. In this period when natural gas markets are increasingly integrated, the findings provide critical implications for energy policies, trade strategies and international relations. The findings of this study also provide a basis for future research and contribute to a more in-depth examination of global natural gas markets.

Future research may aim to further examine the level of integration in global natural gas markets. In particular, going beyond the BEKK and DCC models and using different econometric models and methods can contribute to a more comprehensive understanding of market dynamics. Examining the impact of geopolitical factors in more detail is important, especially in terms of understanding the effects of the recently increasing geopolitical tensions and changes in energy policies on the markets. Additionally, investigating the impact of renewable energy sources and liquefied natural gas (LNG) technologies on markets may be critical to understanding future natural gas market dynamics.

In addition, studying the long-term effects of regional market integrations also provides an important research area. For example, one could investigate how changes in natural gas infrastructure, new pipeline projects, and LNG terminals affect cross-market integration. Additionally, examining the role of different regulatory frameworks and market reforms on integration can provide important information for optimizing energy policies and regulations. Such research will contribute to a better understanding of the complex interactions and integration processes in natural gas markets at both academic and practical levels

DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Reza Bilgin: Authored the whole article.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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