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Assessing the Integration of Natural Gas Markets in Europe and East Asia: An ARDL Approach*

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Avrupa ve Doğu Asya Doğal Gaz Piyasalarının Entegrasyonunun Değerlendirilmesi: Bir ARDL Yaklaşım

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Abstract

This study investigates the relationship between natural gas price dynamics in Europe and East Asia using the Nonlinear Autoregressive Distributed Lag (NARDL) model, which allows for the analysis of both short- and long-term asymmetries in a unified framework. The NARDL approach is particularly appealing due to its simplicity in handling these asymmetries within a single model. The dataset includes daily spot prices for natural gas in East Asia, specifically the LNG Japan/Korea Marker (JKM) obtained from SP Platts covering the period from July 29, 2014, to November 17, 2023. Additionally, daily spot prices from the National Balancing Point (NBP) in the United Kingdom were sourced from Refinitiv Eikon for the same time frame. Findings from the analysis indicate that changes in lagged natural gas prices in one market significantly influence prices in the other. Moreover, the impact of negative price shifts appears to be greater than that of positive shifts, with long-term multiplier effects manifesting over a period of approximately 9 to 12 months.

Keywords: *Natural gas, market integration, LNG, ARDL.*

Makale Bilgileri
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Öz

Bu çalışma, Avrupa (NBP) ve Doğu Asya (JKM) doğal gaz piyasaları arasındaki fiyat dinamiklerini incelemektedir. Araştırma hem kısa hem de uzun vadeli asimetrileri tek bir çerçevede analiz etmeye olanak tanıyan Doğrusal Olmayan Otoregresif Dağıtılmış Gecikme (NARDL) modelini kullanmaktadır. NARDL yaklaşımı, bu asimetrileri tek bir model içinde ele alabildiği için özellikle tercih edilmiştir. Çalışmanın veri seti, 29 Temmuz 2014 ile 17 Kasım 2023 tarihleri arasını kapsamaktadır. Doğu Asya'daki LNG Japonya/Kore Göstergesi (JKM) günlük spot fiyatları SP Platts'tan, Birleşik Krallık'taki Ulusal Denge Noktası (NBP) günlük spot fiyatları ise aynı dönem için Refinitiv Eikon'dan temin edilmiştir. Elde edilen analiz bulguları, bir piyasadaki gecikmeli doğal gaz fiyatlarındaki değişikliklerin diğer piyasadaki fiyatları önemli ölçüde etkilediğini ortaya koymaktadır. Daha da dikkat çekici olan, negatif fiyat değişimlerinin etkisinin pozitif değişimlerin etkisinden daha büyük olmasıdır. Uzun vadeli çarpan etkilerinin ise yaklaşık 9 ila 12 aylık bir süre içinde ortaya çıktığı tespit edilmiştir. Bu sonuçlar, iki bölgesel piyasa arasındaki asimetrik bağlantıyı ve özellikle fiyat düşüşlerinin daha güçlü yayılma etkisine sahip olduğunu göstermektedir.

Anahtar Kelimeler: *Doğal gaz, piyasa entegrasyonu, LNG, ARDL.*

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1. Introduction

Natural gas holds a critical position in modern energy markets, serving as a key factor in ensuring energy security, fostering economic development, and supporting environmental sustainability. As two of the largest natural gas-consuming regions globally, Europe and East Asia significantly influence the dynamics of the international natural gas market through their energy policies and economic strategies.

This research highlights the strategic relevance of integrating natural gas markets in Europe and East Asia, emphasizing its role in strengthening energy security, promoting economic stability, and addressing environmental challenges. Given Europe's historical reliance on Russian gas and Asia's substantial demand for LNG, closer integration between these regions could enhance supply security, stabilize prices, and support international trade. Such integration is vital not only for regional energy strategies but also for maintaining stability in global natural gas markets.

The study aims to reveal the level of integration by analyzing the extent to which price movements and market dynamics in natural gas markets are compatible between Europe and East Asia. It is expected that this integration will contribute to making fluctuations and price changes in energy supply more predictable and manageable. In addition, it is anticipated that this integration can support the achievement of environmental sustainability goals, the increase in the use of renewable energy sources and the reduction of carbon emissions. This study aims to contribute to energy security, price stability and international trade policies by evaluating the level of integration.

The integration of the European and East Asian natural gas markets has been the subject of extensive academic and industry research, due to the fact that, these two regions are important consumption centers with their unique demand dynamics and supply paths. Studies investigating the price convergence between the Asian and European natural gas markets have yielded mixed results. The study by R. Li et al., (2014a) provides evidence of price convergence between the Asian and European markets, indicating that these regions are converging in natural gas price trends. However, some studies, such as the studies by (R. Li et al., 2014a) and (Wu, 2011), emphasize that this convergence has not reached the level of full global integration, and that regional differences prevent the formation of a truly unified global market.

The relationship between the European and Asian gas markets has undergone significant changes over time, especially in terms of price-setting leadership. Before 2011, Asia generally held a dominant position in price setting; this was supported by high demand, especially in countries dependent on LNG (liquefied natural gas) imports, such as Japan and South Korea. However, after 2011, Europe began to take a leading role in the global gas market. (Kim and Kim, 2019) attribute this change to Europe being a flexible demand center with a well-developed infrastructure for pipeline gas and LNG, as well as a strong regulatory environment that encourages carbon pricing and market liberalization.

There are many important factors affecting the integration process. The emergence of “flexible suppliers” that can adjust supply according to regional demand fluctuations has supported this integration by increasing market fluidity. In addition, Japan’s sharp increase in LNG imports after the Fukushima disaster in 2011 and China’s rapidly growing demand for natural gas, especially from Russia, have changed the global supply-demand balance. These dynamics have led to the two regions becoming closer together, but full integration has not occurred.

Market fundamentals in Europe also play a critical role in shaping not only domestic but also international gas prices. As (Kopytin et al., 2022) noted, carbon pricing policies and the use of natural gas storage facilities, which affect the cost differences between natural gas and alternative energy sources, directly affect price volatility. This volatility affects not only Europe but also price trends in the Asia-Pacific market and, to a lesser extent, the US market. Europe’s large storage capacity allows it to act as a balancing force in the market, influencing price fluctuations on a global scale by storing excess gas during periods of low demand and releasing it to the market during periods of increased demand.

Integrating natural gas markets requires examining how price movements and market dynamics are aligned geographically. Market integration implies that the prices of two or more markets converge over time and are influenced by common economic factors. In integrated markets, supply and demand shocks can spread rapidly from one region to another, causing prices to move similarly.

The importance of natural gas market integration between Europe and East Asia is emphasized, especially in terms of energy supply security and price stability. The energy demand and supply chains of these two regions directly influence global natural gas trade flows and price formation. In particular, Europe's historical natural gas dependence on Russia and Asia's high demand for LNG (liquefied natural gas) imports are of critical importance in terms of evaluating price differences and supply security between these regions. While energy policies and market regulations are shaped in line with natural gas supply security and sustainability targets, the integration of natural gas markets in Europe and East Asia can increase the effectiveness of these policies.

A unified market structure can enhance the predictability and control of energy supply variations and price fluctuations. Furthermore, such integration supports environmental objectives, including the expansion of renewable energy usage and the reduction of carbon emissions. As a result, linking the European and East Asian natural gas markets holds critical importance not only for ensuring regional energy security and economic resilience but also for fostering the sustainability of global energy markets and advancing environmental targets. In this regard, reinforcing energy strategies and promoting international collaboration will play a pivotal role in shaping a more stable and sustainable energy landscape in the future.

The integration and interaction of these markets is of great importance in terms of energy consumption, prices and supply-demand balance. Looking at the globalization of natural gas markets, for example, the increase in natural gas demand in Asia in the first quarter of 2021 affected LNG trade and caused an increase in European wholesale spot gas prices. This highlights the globalized nature of natural gas markets (Directorate-General for Energy, 2021). It should be also noted that Asian markets can quickly and significantly affect European hub prices (European Commission, 2021).

Studying European and East Asian natural gas markets Integration helps us understand how the energy strategies and economic dynamics of these two regions affect global natural gas markets. If there is a strong integration between these two markets, natural gas prices are expected to converge over time, in accordance with the Single Price Law. This is because similar economic factors and supply-demand balances are effective in both markets. For example, when there is a supply security crisis in Europe, this may also affect East Asian markets and prices may move similarly in both regions.

To assess the degree of integration between European and East Asian natural gas markets, it is essential to analyze the alignment of prices in these regions. Given that natural gas is produced and consumed in geographically distinct areas, local factors such as transportation costs, regulatory frameworks, and geopolitical risks can influence price disparities. Europe's reliance on Russian natural gas and Asia's substantial demand for LNG are among the factors that can sustain price gaps and pose challenges to market integration. Without achieving full market integration, price alignment remains complex, and discrepancies are likely to persist.

In the first part of our study, we detail the theoretical foundations of the "Law of One Price", its applicability and its reflections on global natural gas markets. In this section, we will analyze the economic meaning of the "Law of One Price", its effects on arbitrage mechanisms and market integration. We will also discuss to what extent price movements in natural gas markets comply with this law and what factors affect this compliance. In the other step, we will delve into the concept of market integration. In this context, we will discuss the integration levels of European and East Asian natural gas markets and the effects of this integration on global natural gas trade. By conducting a literature review, we will evaluate the findings of existing studies and discuss the effects of market integration on energy security, price stability and international trade.

In the last section, we will move on to the analytical part and empirically test the integration of European and East Asian natural gas markets and the applicability of the Single Price Law in the light of theoretical and literary knowledge. In this context, we will evaluate market integration and price compliance using data analysis and econometric modelling. The findings of our study will contribute to the development of policy recommendations for the integration of natural gas markets.

The original contribution of this study is that it empirically tests the level of integration between the European and East Asian natural gas markets within the framework of the “Law of One Price” and structures these tests in a way that is compatible with both the literature and the theoretical background. Thus, the theoretical-empirical integration that is missing in the literature will be provided and the effects of integration on energy security, price stability and environmental sustainability will be evaluated multi dimensionally. In addition, the study aims to not only contribute to the academic knowledge but also to create an analysis ground that includes strategic guidance for policy makers.

As a result, this research aims to eliminate both the theoretical deficiencies and the empirical test deficiencies in the existing literature by providing an in-depth analysis of the level of integration of the European and East Asian natural gas markets. In this context, the study will contribute to the understanding of global interdependence in natural gas markets and the shaping of sustainable energy policies.

The remainder of this paper is organized as follows. Section 2 provides a comprehensive literature review on natural gas market integration, focusing on the theoretical underpinnings of the Law of One Price and Purchasing Power Parity. Section 3 outlines the data sources, variable definitions, and methodological framework, including the ARDL and NARDL models. Section 4 presents the empirical findings and interprets the results of the co-integration and asymmetry analyses. Section 5 discusses the implications of the findings in light of the existing literature, while Section 6 concludes the paper with key takeaways, policy recommendations, and suggestions for future research.

2. Literature Review

LOP (Law of One Price) and PPP (Purchasing Power Parity) have been one of the most debated concepts in economic literature. The former states that, under conditions of market perfection, the price of a commodity or service would be the same across markets after accounting for exchange rate differentials. It suggests that the price of a commodity across countries should be the same when adjusted by the exchange rate. In reality, however, deviations from LOP occur quite often due to influences such as transport costs, differential tax rates, trade barriers, and market inefficiencies. These deviations are considered to be one of the most fundamental measures of the extent of market integration.

Purchasing Power Parity can be considered as an extended version of LOP and is based on the idea that national price levels should be compatible with exchange rates. PPP suggests that exchange rates will be adjusted according to inflation differences between two countries, especially in the long term. However, the literature emphasizes that factors such as price elasticities, trade barriers and capital mobility may prevent the full realization of PPP in the short term. Both LOP and PPP theories are considered as a measure of market integration and constitute an important reference point in the analysis of the level of economic integration between countries. In this context, studies examining the relationship between market integration, exchange rate movements and price levels play an important role in determining international trade and investment strategies.

The Law of One Price (LOP) is a concept that plays a fundamental role in international trade theories and exchange rate determination. The law states that when the prices of a good valid in international trade are expressed in a common currency in two different markets, the price difference is only the transaction costs. In other words, it expresses the theory that the difference between the prices of the same good will be limited only to the costs incurred during the buying and selling transactions.

The Law of One Price (LOP) posits that identical goods should have the same price across different markets when expressed in a common currency, assuming zero transportation and transaction costs. This principle underpins the theory of Purchasing Power Parity (PPP), which extends the LOP to aggregate price levels across countries. As emphasized by (Cassel, 1916) and further elaborated by (Krugman and Obstfeld, 2009), deviations from LOP and PPP may occur due to market imperfections, transport costs, and regulatory differences. These concepts provide the theoretical foundation for evaluating market integration through price convergence (See also: (Crucini and Shintani, 2008); (Rogoff, 1996).

The integration of international natural gas markets has become a central issue in energy economics, especially in the aftermath of global energy crises and rising concerns about energy security. This section provides a thematic review of the literature, grouped under the following categories: (i) theoretical foundations of price parity and market integration, (ii) methodological approaches to measuring integration, and (iii) empirical findings on regional and global natural gas market linkages.

2.1. Theoretical Background: LOP, PPP, and Market Integration

The Law of One Price (LOP) and Purchasing Power Parity (PPP) constitute two of the most fundamental theoretical frameworks underpinning the analysis of market integration, particularly in the context of internationally traded commodities and energy markets. The Law of One Price postulates that in the absence of transportation costs, tariffs, and other market frictions, identical goods should command the same price across different locations when expressed in a common currency. This notion relies on the efficiency of arbitrage mechanisms, whereby price differentials are swiftly eliminated as traders exploit profit opportunities (Isard, 1977). At a more aggregate level, PPP generalizes this concept to overall price indices, asserting that nominal exchange rates should adjust to equalize the price levels of identical consumption baskets between countries (Krugman and Obstfeld, 2009). In this context, market integration is signaled by the tendency of prices or price indices to converge across borders, aligning domestic and foreign markets over time.

However, while both LOP and PPP offer elegant theoretical benchmarks for perfect market integration, empirical investigations frequently reveal persistent and sometimes substantial deviations from these postulates. One of the seminal contributions in this field is (Engel and Rogers, 2001), who demonstrate that even between cities in the U.S. and Canada—countries with deeply interconnected economies—there exist significant price differentials that cannot be fully explained by nominal exchange rate fluctuations. Their findings underscore the role of border effects, transportation costs, and distributional rigidities in weakening the force of arbitrage, thus impeding the realization of the LOP in practice. Moreover, the so-called "PPP puzzle," first articulated by (Rogoff, 1996), captures the empirical observation that real exchange rates exhibit extremely slow mean reversion. Despite the theoretical expectation of long-run parity, convergence to PPP often takes several years or even decades, casting doubt on the practical relevance of PPP in short- to medium-term policy analysis. Various structural and institutional frictions have been proposed to account for this slow adjustment. These include nominal rigidities such as sticky prices and wages (Chari et al., 2002), non-traded goods differentials captured by the Balassa-Samuelson effect (Balassa, 1964); (Samuelson, 1964)), and the influence of transaction costs and market segmentation (Goldberg and Knetter, 1997). Furthermore, in commodity and energy markets, price convergence may also be affected by storage constraints, contractual rigidities, and regulatory heterogeneity, all of which can delay or prevent full arbitrage from materializing.

While LOP and PPP provide essential theoretical foundations for evaluating cross-market integration, especially in the context of globally traded commodities, a growing body of empirical literature suggests that these conditions rarely hold perfectly in practice. The persistent deviations from price parity—both at the micro and macro levels—highlight the importance of considering market frictions, institutional factors, and structural asymmetries when analyzing international price dynamics. These insights are particularly relevant in studies of energy market integration, where cross-border price behavior is subject to geopolitical risks, infrastructure limitations, and varying regulatory environments.

2.2. Measuring Integration in Energy and Commodity Markets

The empirical assessment of market integration, particularly in the context of energy and commodity markets, has evolved considerably over the past decades. Researchers have employed a variety of quantitative methods to evaluate the degree, direction, and speed of price transmission across spatially or institutionally segmented markets. Among the most widely used techniques are price correlation analysis, cointegration tests, error correction models (ECM), and volatility-based frameworks such as GARCH, BEKK-GARCH, and DCC-GARCH models. These methods provide insights not only into the co-movement of prices but also into the dynamic adjustment processes that follow price shocks, thereby offering a nuanced understanding of short- and long-term market integration (Asche et al., 2001), and (Silvennoinen and Thorp, 2013).

The foundation for empirical analysis in this field can be traced back to (Balassa, 1964), who emphasized the importance of testing the Purchasing Power Parity (PPP) hypothesis within the broader context of trade openness and exchange rate behavior. This early work inspired a generation of research seeking to understand how and to what extent price signals transmit across borders and market segments. Subsequent studies such as (Goodwin and Schroeder, 1991) and (McNew, 1996) advanced the spatial price transmission framework, proposing that a fully integrated market is characterized by the complete and immediate transmission of price shocks from one region to another. In such a market, arbitrage ensures that local shocks are neither isolated nor persistent.

(Egger et al., 2009) offer a more refined measure of integration by estimating deviations from the Law of One Price (LOP) for tradable goods across OECD countries. Their results suggest a half-life of deviations ranging from 2.2 to 6.3 years, indicating that while convergence exists, it unfolds slowly over time. These findings highlight the importance of transaction costs, regulatory heterogeneity, and supply chain frictions in shaping the temporal dimension of market integration. Importantly, these spatial integration techniques have since been adapted to the context of commodity and energy markets, where price behavior is often influenced by geopolitical risks, supply-demand asymmetries, and infrastructure bottlenecks. Beyond physical market linkages, financial instruments and exchanges also play a pivotal role in fostering integration. The development of futures markets and commodity derivatives has enhanced price discovery, improved market transparency, and reduced arbitrage costs. For instance, (Garcia and Leuthold, 2004) demonstrate that futures trading leads to more efficient pricing in agricultural markets. The analogy extends to energy markets, where futures contracts for oil, natural gas, and electricity not only facilitate hedging but also synchronize price expectations across regions.

Similarly, studies in financial integration provide additional tools and analogies for assessing market cohesion. (Ferrando and Vesala, 2018) emphasize that price-based indicators in bond and money markets—such as interest rate differentials and yield curve dynamics—can signal degrees of integration. These indicators, when applied to energy pricing mechanisms (e.g., spot-futures spreads or regional basis differentials), allow researchers to infer the degree of connectedness and efficiency in energy markets. The measurement of market integration in energy and commodity markets is inherently multidimensional, requiring the combined application of price-based econometric models, structural characteristics of trade networks, and insights from financial market behavior. These methodological approaches enable scholars to capture both the instantaneous co-movements and long-run equilibria that define truly integrated markets.

2.3. Empirical Studies on Natural Gas Market Integration

The empirical literature on natural gas market integration has grown considerably over the past two decades, offering insights into the extent, dynamics, and heterogeneity of price linkages both within and across regional gas markets. A central theme in this body of work is the question of whether natural gas prices exhibit a pattern of convergence consistent with integrated and competitive markets. Although theoretical models often assume efficient price transmission, real-world factors such as infrastructure limitations, contractual rigidities, and region-specific pricing mechanisms frequently result in partial or asymmetric integration.

One of the pioneering studies in this domain is that of (Siliverstovs et al, 2005), who investigated the degree of market integration among Europe, North America, and Japan using Johansen co-integration techniques. Their empirical analysis revealed strong evidence of price convergence within regional blocs—notably between U.S. hubs and among European trading points—but limited or weak co-integration across regions, particularly between Europe and Asia. The authors attributed these results to structural constraints such as insufficient LNG infrastructure, long-term contract structures, and differences in market liberalization processes. This early study provided a foundational basis for distinguishing between intra-regional and inter-regional integration in global gas markets.

Expanding on this regional focus, (Wilmot and Taivan, 2017) examined the interconnectedness of U.S. and Canadian energy markets using Granger causality tests and error correction models (ECM). Their findings point to a bidirectional causality in crude oil prices, indicative of high levels of integration, whereas natural gas markets displayed asymmetric and incomplete integration, with weak error-correction mechanisms. This suggests that while there is significant short-run interaction between U.S. and Canadian gas markets, the long-run equilibrium adjustment is less robust, reflecting infrastructural or regulatory frictions specific to the natural gas sector.

In a more advanced methodological setting, (McNew, 1996) and (Li et al., 2014a) employed Ensemble Empirical Mode Decomposition (EEMD) in conjunction with minimum spanning tree (MST) algorithms to analyze the multi-scale dynamics between spot and futures prices in the European and Japanese gas markets. Their approach enabled a frequency-domain decomposition of price signals, uncovering that futures markets—particularly for residential and commercial gas segments—exert a leading influence over spot markets. These findings underscore the growing informational efficiency of derivative markets, as futures contracts increasingly serve as benchmarks for physical gas transactions and price expectations.

A broader, cross-commodity perspective is offered by (Chuliá et al., 2019a), who analyzed volatility interactions among five major energy markets: electricity, natural gas, oil, coal, and carbon permits, across Europe and the United States. Utilizing a comprehensive dataset of forward prices and advanced volatility transmission models, they observed that natural gas prices were the primary source of volatility spillovers to other energy commodities. Furthermore, their results identified key pricing hubs within Europe—most notably the Netherlands' Title Transfer Facility (TTF) and Germany's NetConnect Germany (NCG)—as central nodes in regional integration. In contrast, countries such as Spain and Italy exhibited lower degrees of market convergence, reflecting uneven progress in market liberalization and infrastructure connectivity across the EU.

Incorporating game-theoretic and network-based modeling techniques, (Mousavian et al., 2021) investigated the strategic interactions between electricity and gas markets by applying a Nash–Cournot equilibrium model that accounts for the physical characteristics of gas transmission systems. Their results emphasize the nonlinear interdependence between infrastructure constraints and pricing behavior, revealing that capacity limits, congestion, and load management decisions can significantly influence the path and extent of price integration. This modeling framework provides a valuable complement to traditional econometric approaches by introducing strategic behavior and system-level constraints into the analysis.

Complementary insights are provided by Liang and (Liang and Kapusuzoglu, 2016) who analyzed the co-integration relationships among natural gas prices in the U.S., Europe, and Japan using both short- and long-term tests. Their findings confirm the existence of regional convergence patterns, particularly within the U.S. and European markets, but also reveal persistent divergences across regions, largely due to contractual heterogeneity, LNG market segmentation, and regulatory disparities. These conclusions are consistent with those of (Renou-Maissant, 2012), who examined the evolution of gas market reforms across Western Europe. Despite notable progress in price convergence, her study finds that full integration remains incomplete, with certain member states exhibiting sticky price behavior and delayed adjustment processes, often due to national-level regulatory or infrastructural inertia. Taken together, these empirical studies highlight the complex, layered, and region-specific nature of natural gas market integration. While evidence of strong intra-regional price linkages exists—particularly in liberalized and infrastructure-rich settings—global convergence remains constrained by a combination of physical, institutional, and economic barriers. The diversity of methodologies—from co-integration and causality tests to network models and volatility spillover frameworks—illustrates the need for multi-method approaches to fully capture the evolving dynamics of gas market integration in a globalized energy landscape.

2.4. Structural Barriers and Geopolitical Dimensions

Despite the theoretical expectation of price convergence under integrated energy markets, structural constraints and geopolitical complexities continue to pose significant barriers to full natural gas market integration. A growing body of literature emphasizes the physical, institutional, and political impediments that shape regional market dynamics and hinder global price alignment.

(Kim and Kim, 2019), (Li et al., 2014a), and (Albrizio et al., 2023) point to a series of persistent bottlenecks, including insufficient LNG regasification and export infrastructure, limited cross-border pipeline connectivity, and heterogeneous regulatory environments. These limitations restrict arbitrage opportunities and prolong market segmentation. For instance, the lack of flexible LNG receiving terminals in several Asian and Southeastern European countries creates localized supply constraints, even when global supply is abundant. Moreover, long-term, take-or-pay contracts further reduce the responsiveness of physical flows to short-term price signals.

One of the core factors contributing to global gas price divergence lies in the regional differences in pricing mechanisms. Asia's reliance on oil-indexed contracts, such as the Japan Crude Cocktail (JCC) benchmark, structurally decouples gas prices from supply–demand dynamics in the gas market itself. This contrasts sharply with North America's Henry Hub system, which is based on spot pricing and reflects real-time supply-demand conditions. Europe, for its part, has gradually moved toward hybrid pricing systems that combine hub-based indices (e.g., TTF, NBP) with legacy oil-linked contracts. These contrasting price formation mechanisms create persistent disparities across regions, making global convergence elusive even in the presence of improved trade infrastructure.

Geopolitical tensions further complicate integration by introducing uncertainty, supply risk, and strategic distortions. The European Union's dependency on Russian gas exports has long been a structural vulnerability. Supply disruptions—whether actual (e.g., 2006, 2009 gas disputes) or anticipated—have led to significant price volatility and prompted costly diversification strategies. Similarly, Asia's heavy reliance on LNG imports from politically sensitive regions, particularly the Middle East, exposes countries like Japan, South Korea, and China to geopolitical shocks that may not affect other markets simultaneously. (Chyong, 2019) offers a detailed analysis of the EU's market liberalization policies, highlighting considerable achievements in enhancing price transparency, promoting inter-hub competition, and developing cross-border capacity mechanisms. However, Chyong also underscores that these reforms remain vulnerable to external shocks and internal fragmentation. In particular, the Russia–Ukraine conflict has reshaped Europe's gas sourcing strategies, accelerating LNG infrastructure investment but also exposing long-standing asymmetries in storage and transmission capabilities. Additionally, the energy transition agenda, while aiming for de-carbonization and supply diversification, introduces new uncertainties about long-term investment incentives in traditional gas infrastructure.

2.5. Implications for Natural Gas Market Integration Studies

In summary, the literature clearly indicates that natural gas markets have made substantial strides toward regional integration, particularly within liberalized and physically interconnected markets such as those in Europe and North America. The development of spot trading hubs increased cross-border infrastructure, and gradual regulatory harmonization have facilitated greater price convergence and market responsiveness in these regions. However, at the global level, the persistence of pricing asymmetries, geopolitical tensions, and structural rigidities continues to constrain full integration, especially between geographically distant and structurally divergent markets such as those of Europe and East Asia.

Empirical studies consistently demonstrate that price convergence is more likely to occur in settings where physical interconnectivity (e.g., pipelines, LNG terminals), market transparency, and competitive trading mechanisms are well established. In contrast, regions characterized by oil-indexed pricing regimes, limited infrastructure capacity, or strategic dependencies exhibit only partial or weak forms of integration. These observations reinforce the notion that market structure, institutional maturity, and geopolitical positioning are critical mediating variables in the process of integration.

From a methodological standpoint, the application of Autoregressive Distributed Lag (ARDL) and Nonlinear ARDL (NARDL) models has gained increasing prominence in the study of energy market dynamics. These models are particularly well suited for examining markets where variables may exhibit different orders of integration, and where short-term disequilibria may diverge from long-run equilibria. Furthermore, the NARDL approach enhances traditional ARDL modeling by allowing for asymmetric adjustments, capturing the real-world complexities of energy markets, where positive and negative shocks may not transmit symmetrically. This is especially relevant in the case of natural gas, where supply disruptions, seasonal fluctuations, and price stickiness often produce nonlinear market responses. By synthesizing both theoretical insights and empirical findings, this study positions itself within a robust academic tradition while simultaneously addressing a critical research gap. Specifically, the analysis focuses on the integration dynamics between the European natural gas benchmark (NBP) and the East Asian spot LNG benchmark (JKM). Employing a high-frequency daily dataset, the study applies asymmetric ARDL modeling to uncover the short- and long-run transmission mechanisms linking these two major regional markets. In doing so, it captures both the direction and intensity of spillovers, while accounting for structural discontinuities and market-specific asymmetries.

The findings are expected to yield important implications for policymakers, regulators, and market participants seeking to enhance price transparency, energy security, and market efficiency in an increasingly interconnected yet fragmented global gas landscape. Moreover, the study contributes methodologically by demonstrating how advanced time-series models can be tailored to address the complexities inherent in global energy markets, thereby enriching the broader discourse on commodity market integration.

Table 1 provides a comprehensive overview of key empirical studies investigating natural gas market integration across various regions and time periods. Collectively, these studies employ a diverse set of econometric and analytical methodologies, including cointegration analysis, error correction models (ECM), Granger and Toda-Yamamoto causality tests, multivariate GARCH models, and network-based approaches such as Ensemble Empirical Mode Decomposition (EEMD) and Minimum Spanning Trees. The findings consistently highlight a greater degree of regional integration, particularly within Europe and North America, as seen in the work of (Siliverstovs et al, 2005) and (Renou-Maissant, 2012), while indicating limited intercontinental convergence, especially between Europe, Japan, and North America (Liang and Kapusuzoglu, 2016). Notably, (Chuliá et al., 2019a) emphasize the rising importance of natural gas over crude oil as a benchmark in EU markets, and (Mousavian et al., 2021) reveal the strategic interdependence between electricity and gas markets. Studies such as (Wilmot and Taivan, 2017) and (Łęt, 2017) further illustrate that while certain markets exhibit causality or volatility linkages, full integration remains constrained by structural and institutional barriers. Finally, (Chyong, 2019) underscores the role of liberalization and regulatory reforms in enhancing integration, while cautioning that geopolitical risks and asymmetric infrastructure continue to pose significant challenges. This table thus reflects the evolution of methodological approaches and the heterogeneity of integration outcomes across time and geography.

Table 1. Researches on Natural Gas Market Integration

Autor(s)	Countries/Regions	Period	Methodologies	Findings
Siliverstovs et al. (2005)	Europe, North America, Japan	1990-2004	Cointegration analysis, PCA, ECM	Regional integration of natural gas markets; divergence between Europe/Japan and North America; oil price significant.
Wilmot and Taivan (2017)	United States, Canada	1980-2015	Johansen cointegration, Granger causality, Toda-Yamamoto causality	Bidirectional causality in US-Canada crude oil; unidirectional causality in natural gas production.
Mousavian et al. (2021)	Global (focus on gas and electricity)	Contemporary	Analytical models, KKT approach, Nash-Cournot equilibrium	Interdependence of natural gas and electric markets; implications for decision makers in energy systems.
Li et al. (2014b)	Europe, Japan, North America	2000-2018	EEMD, Minimum Spanning Trees	High integration between futures and physical markets; efficient price information transmission.
Chuliá et al. (2019a)	Europe (multiple countries), USA	2006-2016	Comprehensive analysis of market linkages	Natural gas surpassing crude oil as a benchmark; importance of integration for EU energy markets.
Łęt (2017)	USA, Europe	2005-2016	Multivariate GARCH model	Insignificant correlation between NBP and HH returns; low correlation between gas and oil returns.
Liang and Kapusuzoglu (2016)	Europe, Japan, USA	2000-2010	Cointegration test, Granger causality	Limited intercontinental market interaction; liberalization leads to market integration in continental regions.
Renou-Maissant (2012)	Western Europe	2000-2010	Cointegration analysis, time-varying parameter models	Ongoing integration of European gas markets; impact of reforms on consumer prices.
Chyong (2019)	Europe	Contemporary	Transaction cost economics framework	Liberalization benefits consumers with lower prices and competition; challenges from geopolitical factors.

There are different methods of measuring integration in natural gas markets, including price correlation, co-integration, causality, and spatial equilibrium models. These methods use different types of data, such as spot prices, futures prices, trade flows, transport costs and capacity constraints, to assess the degree and dynamics of market integration.

3. Data and Methodology

In this study, we used a comprehensive data set to examine market integration between East Asian natural gas spot prices and the UK's national balancing point (NBP) spot prices. The data includes daily prices between July 29, 2014, and November 17, 2023. East Asian natural gas spot prices are provided by S&P Platts as LNG Japan/Korea Marker (JKM) prices and obtained via www.investing.com. NBP spot prices for the same period were obtained from Refinitiv Eikon. Table 2 shows variables and source of the variables.

Table 2. Data Description

Variable	Explanation	Source
JKM Price	East Asian natural gas spot prices	S&P Platts via www.investing.com
NBP Price	UK's national balancing point (NBP) spot prices	Refinitiv Eikon

Table 3 shows descriptive statistics of our data. Descriptive statistics are statistical methods used to summarize the basic features of a data set. These methods provide an overview of the data before analyzing it, allowing us to gain information about the data. Descriptive statistics are often used to understand the center, distribution, and shape characteristics of the data.

Table 3. Descriptive Statistics

	JKM Price	NBP Price
Mean	11.16514	8.890255
Median	7.428750	6.360004
Maximum	69.95500	67.47530
Minimum	1.995000	1.077689
Std. Dev.	10.35893	8.693166
Skewness	2.349592	2.916371
Kurtosis	8.508416	12.94009
Jarque-Bera	4713.880	11943.29
Probability	0.000000	0.000000
Observations	2158	2158

Table 3 provides important findings regarding the price dynamics of both markets. When the price averages are examined, it is seen that the average price for JKM Price is 11.16514 and for NBP Price it is 8.890255. This situation indicates that East Asia natural gas prices are generally higher than UK prices. The median values are 7.428750 and 6.360004, respectively, and the median values of both variables are lower than the mean. This difference indicates that there is a positive skew in the price distributions, i.e., high price values pull the mean up.

When the maximum and minimum values of the price series are taken into account, it is understood that both markets fluctuate in a wide price range. While the highest value for JKM Price is 69.955 and the lowest value is 1.995; For NBP Price, these values were determined as 67.4753 and 1.077689, respectively. These results are an indication of high volatility in prices. Standard deviation values were calculated as 10.35893 for JKM Price and 8.693166 for NBP Price; these values reveal that the price series are highly variable and that prices can deviate significantly from the mean.

The skewness and kurtosis values of both price series are also remarkable. The skewness value of JKM Price was found as 2.349592 and the skewness value of NBP Price was found as 2.916371, and it is seen that both variables exhibit a positively skewed distribution. This indicates that high values are more frequent in price series and that the distribution is skewed to the right. When looking at the kurtosis values, it was calculated as 8.508416 for JKM Price and 12.94009 for NBP Price; both values being greater than 3 indicate that the distribution is leptokurtic, that is, the data set is concentrated towards extreme values. This indicates that extreme values are seen more frequently than expected in the price series and that the distribution has a high peak.

When the Jarque-Bera test statistic and its p-values are examined, it is understood that both series do not show a normal distribution. The Jarque-Bera statistic for JKM Price was found as 4713.880 and for NBP Price as 11943.29; the p-values of both series are 0.000000, rejecting the assumption of normal distribution. These results prove that the JKM Price and NBP Price series do not exhibit normal distribution and have an asymmetric distribution structure.

To summarize, the JKM Price and NBP Price series present price movements that exhibit high means, wide fluctuations, right-skewed distribution and high kurtosis. This analysis shows that high volatility and asymmetric distribution are prominent in both price series, indicating that caution should be exercised in modelling these prices.

First, we used the ARDL (Autoregressive Distributed Lag) model to analyze the long-term relationship between these two-price series. The ARDL model has the ability to simultaneously evaluate long-term relationships and short-term dynamics in time series data. This method is suitable for both stationary and non-stationary time series and is ideal for determining whether a cointegration relationship exists between the series.

Following the ARDL model, we applied the NARDL (Nonlinear Autoregressive Distributed Lag) methodology to examine the asymmetric effects of price changes. The NARDL method allows analyzing asymmetric reactions in prices by evaluating the effects of positive and negative shocks separately. This method was developed with the assumption that markets may respond differently to positive and negative price changes, and in this study, it helped identify asymmetric effects in prices.

ARDL bound test is a co-integration technique used to test the long-run relationship between variables with different levels of integration. It has many advantages (Nkoro and Uko, 2016) and (Alper, 2017): Unlike other cointegration methods, it does not require large samples and can be applied to small or limited samples. It allows different lag structures for each variable, allowing for greater flexibility and efficiency in model specification. It can identify multiple cointegration vectors and estimate short-run and long-run coefficients simultaneously. It can deal with structural breaks or regime changes in the data and can handle these situations by adding dummy variables or trend terms.

The ARDL bound formula of our model is as follows:

$$\Delta NBP = \theta_0 + \sum_{q=1}^{p1} \theta_{1q} \Delta NBP_{t-q} + \sum_{q=0}^{p2} \theta_{2q} \Delta JKC_{t-q} + \alpha_1 JKC_{t-1} + \varepsilon_t \tag{1}$$

The NARDL model is a way to analyze the relationship between a dependent variable and one or more explanatory variables in both the short and long term. It also takes into account possible nonlinearities and asymmetries (González et al., 2020).

To investigate the asymmetric relationship between natural gas prices across different regions, the Nonlinear Autoregressive Distributed Lag (NARDL) model is employed. Unlike the traditional ARDL framework, which assumes a symmetric and linear adjustment between variables, the NARDL model (Shin et al., 2014a) allows for potential asymmetric long- and short-run effects. In other words, it can detect whether positive and negative changes in one variable (e.g., Asian gas prices) have different effects on another variable (e.g., European gas prices). This flexibility is particularly useful in commodity markets like natural gas, where price movements are often influenced by region-specific shocks, political interventions, and infrastructure constraints that might not affect all markets equally.

To clarify the intuition behind the NARDL model, consider a simple example:

Suppose we want to understand how natural gas prices in East Asia (X) affect prices in Europe (Y). The NARDL model first decomposes the changes in X into two separate components:

Positive changes in X: ${x_t}^+$ (increases in East Asian gas prices)

Negative changes in X: ${x_t}^-$ (decreases in East Asian gas prices)

These components are cumulatively constructed as follows:

$$ {x_t}^+ = \sum_{j=1}^{t} \Delta x_j^+ = \sum_{j=1}^{t} max(\Delta x_j, 0), {x_t}^- = \sum_{j=1}^{t} \Delta x_j^- = \sum_{j=1}^{t} min(\Delta x_j, 0) \quad (2) $$

Some advantages of the NARDL model are (Shin et al., 2014b) and (Allen and McAleer, 2020) as follows. It can be estimated by the ordinary least squares (OLS) method, which is simple and efficient. The levels of integration of dependent variables do not need to be the same, so it uses bounds testing for reliable long-term inferences. This can deal with both stationary and non-stationary time series, or a mixture of the two (González et al., 2020). It can capture the different effects of positive and negative changes in explanatory variables on the dependent variable in both the short and long term. This can provide important insights into the nature and direction of the causal relationship. This method is highly suitable for energy market studies where price responses to global shocks may vary by direction and region. For instance, a price spike due to supply disruptions may have a greater or more immediate impact than a price drop caused by seasonal demand decline. The choice of the NARDL model is justified by the objective of this paper, which is not only to assess whether there is a long-term co-integration between regional gas markets but also to explore whether the adjustment mechanisms differ depending on the direction of price changes. This model enables the capture of such nonlinear dynamics, making it superior to linear alternatives like standard ARDL or VECM models when asymmetry is theoretically or empirically plausible.

And β^+, β^- are the related asymmetric long-run elements. error-correction form of the system is as follows:

$$ \Delta y_t = \rho y_{t-1} + \theta^+ x_{t-1}^+ + \theta^- x_{t-1}^- + \sum_{j=1}^{p-1} \gamma_j \Delta y_{t-j} + \sum_{j=0}^{q} (\pi_j^+ \Delta x_{t-j}^+ + \pi_j^- \Delta x_{t-j}^-) + \varepsilon_t, \quad (3) $$

where null hypothesis $\rho = \theta + = \theta - = 0$

NARDL formula of our model is as follows:

$$ \Delta NBP = \theta_0 + \sum_{q=1}^{p1} \theta_{1q} \Delta NBP_{t-q} + \sum_{q=0}^{p2} \theta_{2q} \Delta JKC_{t-q}^{pos} \sum_{q=0}^{p2} \theta_{3q} \Delta JKC_{t-q}^{neg} + \alpha_1 JKC_{t-1}^{pos} + \alpha_2 JKC_{t-1}^{neg} + \varepsilon_t \quad (4) $$

The regression and correlation approach are methods of testing market integration by examining the degree of price convergence in different markets. This is based on the assumption that if two prices are integrated, they should have a stable and positive relationship in the long run. Many studies such as (Muwanga and Snyder, 1999), (Tavares and Morgado, 2006), and (Wang and Moore, 2008) have used regression and correlation Approach for testing market integration. The correlation approach estimates the following equation (Muwanga and Snyder, 1999):

$$ P_{it} = \beta_0 + \beta_1 P_{jt} + \varepsilon_{it} \quad (5) $$

If two prices of P_{it} and P_{jt} are integrated, a long-run correlation relationship exists. The null hypothesis of $\beta_1 \neq 1$ is against $\beta_1 = 1$.

In case $\beta_1 \neq 1 \rightarrow$ imperfect market integration or market segmentation holds in the long-run.

In case $\beta_1 = 1 \rightarrow$ law of one price or perfect market integration holds in the long-run

The law of one price carries many assumptions such as deep and wide market, zero transaction cost, zero transportation cost, no market concentration, 0 market power. The law of one price is limited in reality because of: Transaction costs, Transportation costs, Legal restrictions, Market structure

4. Empirical Findings or Results

As mentioned, this study aims to examine in depth the relationship between natural gas spot prices in East Asia and the UK's national balancing point spot prices. LNG Japan/Korea Marker (JKM), which is represented in the East Asian markets, used the prices on a daily basis. In the first step of the study, the data series were subjected to correlation, unit root testing and then, based on these test results, ARDL and NARDL models were used as the appropriate model.

ARDL (Autoregressive Distributed Lag) model is an econometric method used to examine long-term relationships between variables in time series data. This model works effectively in time series where stationary and non-stationary variables coexist. The ARDL model determines the most appropriate lag structures by looking at the stationarity properties of both the dependent variable and the independent variables, allowing to model long-term interactions accurately.

The NARDL (Nonlinear Autoregressive Distributed Lag) model is an extended version of the ARDL model and is used to examine the asymmetry in the relationships between variables. The NARDL model is suitable for revealing the asymmetric effects between variables and the changes of these effects over time, by considering the effects of positive and negative shocks separately. With these features, the NARDL model is considered an important tool in econometric analysis, especially in examining complex relationships such as price dynamics.

4.1. Correlation Analysis

As mentioned, in this study, the long-term relationship between JKM prices and NBP prices and the asymmetric effects of these prices were investigated in detail by applying ARDL and NARDL analysis methods on the data set collected on a daily basis between 29 July 2014 and 17 November 2023.

Before analysis, correlation coefficients were examined to obtain a deeper understanding of the existence of a strong relationship between two variables and the nature of this relationship. This initiative lays the groundwork for the main objectives of the study and the interpretation of the findings, thus aiming to make a significant contribution to understanding price movements in energy markets and predicting future market behavior. Table 4 shows coefficient of correlation test.

Table 4. Correlation Analysis

Correlation coefficient (Probability)		
	JKM Price	NBP
JKM Price	1	0.923805 (0.000)
NBP Price	0.923805 (0.000)	1

According to the results of this correlation coefficient, there is a very strong and positive relationship between JKM prices and NBP prices. The correlation coefficient was calculated as

0.923805 and this value was found to be statistically significant ($p < 0.001$). In other words, it can be said that the daily price changes between JKM prices and NBP prices move largely in the same direction and together. This result shows that the relationship in natural gas prices between East Asian and UK markets is strong and stable.

The Unit Root Test is a statistical method used to assess whether a time series is stationary or not. A unit root suggests that the time series is non-stationary, meaning its mean tends to grow over time rather than remaining constant. Non-stationarity can complicate time series analysis and forecasting, which is why conducting unit root tests is crucial for reliable results. Several unit root tests exist, with the Dickey-Fuller test being one of the most commonly used. This test involves calculating a statistic to assess whether a time series possesses a unit root. The primary hypothesis in this test is to reject the existence of a unit root, implying the series is stationary.

A unit root test generally evaluates whether a series is stationary or exhibits a unit root. The null hypothesis typically posits the presence of a unit root (non-stationarity), while the alternative hypothesis suggests stationarity or a trend-stationary process. For example, in the Augmented Dickey-Fuller (ADF) test, the hypotheses are as follows:

- Null Hypothesis (H_0): The series has a unit root, meaning it is non-stationary.
- Alternative Hypothesis (H_1): The series is stationary, implying no unit root.

In the case of ADF test results, if the test statistic exceeds a critical value, the null hypothesis is rejected, and the series is considered stationary. On the other hand, if the statistic is smaller than the critical value, the null hypothesis is not rejected, indicating the series is non-stationary and likely has a unit root. The results of unit root tests are shown in Table 5 as follows:

Table 5. Unit Root Tests Results

Variables	**ADF[1]**		**PP[2]**	
	Include Intercept	Include Trend and Intercept	Include Intercept	Include Trend and Intercept
JKM	-1.82(0)	-2.51(0)	-1.73(12)	-2.43(12)
ΔJKM	-48.13(0)***	-48.13(0)***	-48.16(11)***	-48-16(11)***
NBP	-2.93(9)**	-3.36(9)**	-4.06(26)***	-4.78(23)***
Δ NBP	-21.31(8)***	-21.30(8)***	-51(38)***	-51.80(38)***

Note: The symbols *, **, and *** denote significance levels of 10%, 5%, and 1% or lower, respectively. The probability values are based on one-sided p-values according to MacKinnon (1996).

Based on Table 5, in our results, we used ADF (Augmented Dickey-Fuller) and PP (Phillips-Perron) tests. Both of these tests, test for the presence of a unit root. So, if you reject the null hypothesis, you can say that the time series is stationary. To reject the null hypothesis, the test statistic must be smaller than the critical value (larger in absolute value) or the p-value must be smaller than a certain significance level (usually 5% or 1%).

Based on Table 5, we found no evidence that the variables NBP have unit roots. Because the test statistics are larger than the critical values and the p-values are not significant. In case of JKM we cannot reject null hypothesis of having unit root. However, when you take the first differences of these variables (ΔJKM and ΔNBP), the test statistics are much smaller than the critical values and the p-values are very close to zero. This indicates that these JKM is first difference stationary, that is, the unit root process is integrated of order one (I(1)) and NBP is stationary at I(0). Therefore, none of variable is stationary at I (2). According to the results of Table 5, JKM is stationary at I(I) and NBP is stationary at I(0).

[1] Based on AIC
[2] Based on Bartlett Kernel

Hence, variables are stationary in a combination of I(0) and I(1). Therefore, ARDL bound developed by (Pesaran et al., 2001) and NARDL model developed by (Shin et al., 2014a) that refer to combines a non-linear long run relationship with nonlinear and asymmetric error correction by use of constructed partial sum decompositions have been considered.

Before estimating ARDL and NARDL model we test best lag for best ARDL model. The importance of the top 20 fit ARDL models that best comply with the Akaike Information Criterion (AIC) is that they represent the best balance between model complexity and data fit. While AIC measures how well a model explains the data, it also penalizes models that use an excessive number of parameters. The lower the AIC, the better the model. However, AIC does not provide a definitive ranking, but a range of plausible models that can be compared based on their relative AIC values. Therefore, it is useful to consider the top 20 models with the lowest AIC values rather than just the single best model to account for model uncertainty and variability[3] (Ingram, 2021). The top 20 models are available to assess the robustness of the results by checking whether main effects and interactions are consistent across different models. They also check the performing model averaging to combine coefficient estimates and standard errors from different models, weighted by their AIC values, and Making model selection by choosing the simplest model that is below a certain threshold value (usually 2 or 4).

Figure 1 and Figure 2 show top 20 model for both ARDL and NARDL model.

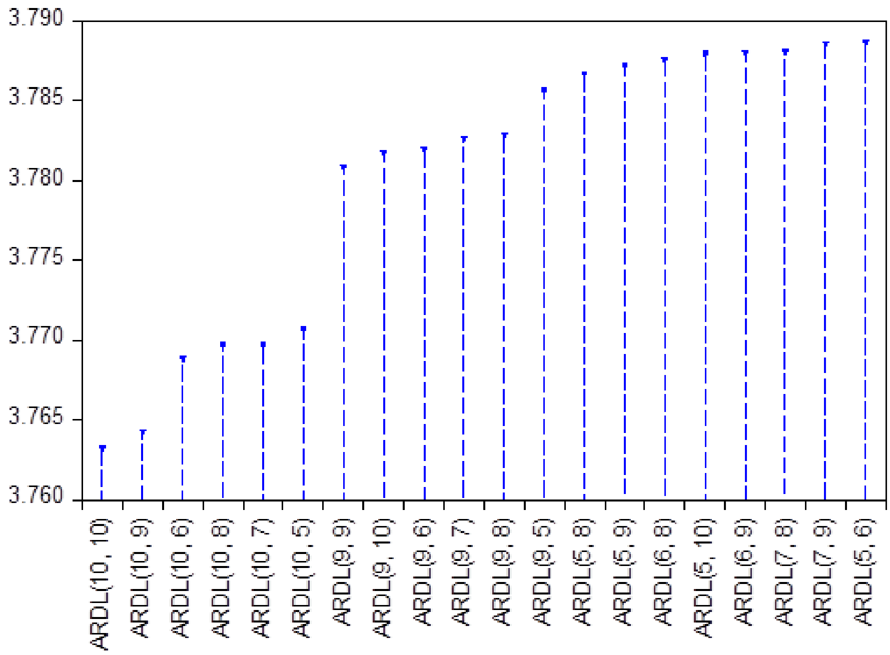

Figure 1. Akaike Information Criteria, Top 20 Model of ARDL Model

Figure 2 shows that the best model according to Akaike Information Criterion (AIC) is ARDL (5,6). This model was estimated using the ARDL method and includes dependent variables with 5 lag terms and independent variables with 6 lag terms. The fact that the ARDL (5,6) model has the lowest AIC value shows that the model has a structure that explains the data best and reduces complexity by using the least parameters. This shows that the overall performance of the model is high and provides a better fit compared to other models. Choosing the ARDL (5,6) model can help obtain more accurate results in data analysis and increase the reliability of future predictions. In case of NARDL model Equation 5, the best model of NARDL model is shown in Figure 1.

[3]https://www.eviews.com/help/helpintro.html#page/content/ardl-stimating_ARDL_Models_in_EViews.html

According to Figure 2, the best model for NARDL model is NARDL (12,11,11).

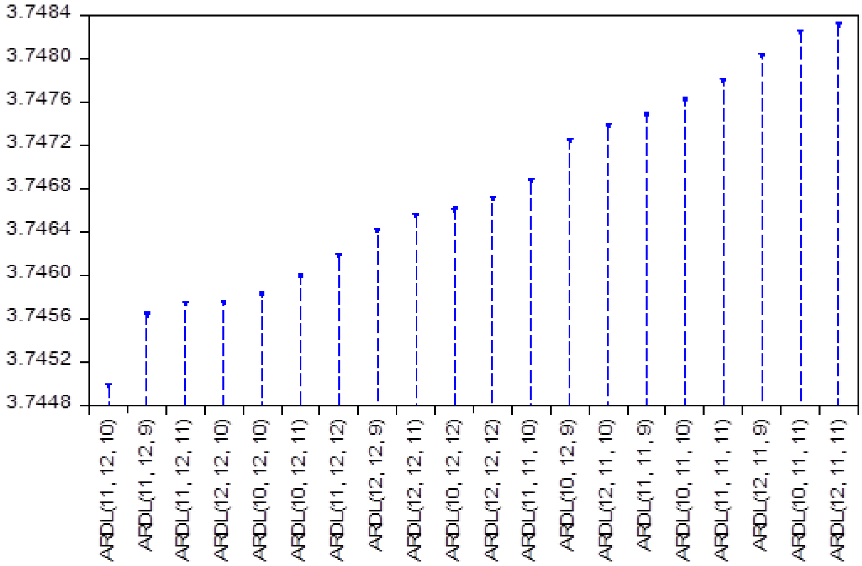

Figure 2. Akaike Information Criteria, Top 20 Models

Figure 2 shows that the best model according to Akaike Information Criterion (AIC) is NARDL (12,11,11). This model was estimated using the NARDL method and includes dependent variables with 12 lag terms and two independent variables with 11 lag terms. The fact that the NARDL (12,11,11) model has the lowest AIC value shows that the model has a structure that explains the data best and reduces complexity by using the least parameters.

This shows that the overall performance of the model is high and provides a better fit compared to other models. Choosing the NARDL (12,11,11) model can help obtain more accurate results in data analysis and increase the reliability of future predictions. Identifying this pattern can be a valuable tool for better understanding the complexity and relationships in the data set.

After selecting best models in the next step the long run relationship of variable is estimated.

Table 6 shows the estimation of the long-run coefficients of our appointed ARDL and NARDL model (Table 6, Equation 5).

Table 6. Long Run Coefficient Model (Dependent Variable **NBP**), Full Sample

Variables	ARDL (5,6) Long Run Coefficients	NARDL (12,11,11) Long Run Coefficients
C	0.79* (1.6)	8.91*** (10.78)
JKM	0.717*** (21.27)	-
JKC^{pos}	-	0.97*** (9.18)
JKC^{neg}	-	1.002*** (8.67)
ECT_{-1}	-0.10***[4] (-8.43)	-0.07***[5] (-4.49)
F-Bounds	24.73*** (upper bound of 1%=5.58)	7.06*** (upper bound of 1%=5)
χ^2_{Serial}	0.59 (Prob.> 0.10)	1.65 (Prob.> 0.10)

Note: ***, ** and * indicates the 1%, 5%, and 10% significance levels, respectively.

[4] $ECT_{-1} = NBP - (0.71JKC + 0.79)$
[5] $ECT_{-1} = NBP - (0.97JKC^{pos} + 1.001JKC^{neg} + 8.91)$

When the estimates of the long-term coefficients of the ARDL and NARDL models are examined, it is seen that the effects of certain variables are examined in both models. Table 6presents the estimates of the long-run coefficients of the ARDL and NARDL models.

In the ARDL model, long-term coefficients of variables such as NBP (National Balanced Point) and JKM (LNG Japan/Korea Marker) were calculated. In the NARDL model, long-term coefficients of variables such as NBP, JKM, JKM positive and JKM negative were estimated.

When the results are examined, it is seen that the long-term coefficients of the NBP and JKM variables are statistically significant in both models.

ECT (Error Correction Term) coefficients in the table are a term used in ARDL and NARDL models. This term refers to the long-term equilibrium relationship and short-term dynamics between the variables in the model. The coefficient of ECT should generally be between -1 and 0, as this indicates the tendency of the model to return to equilibrium quickly.

It can be observed that the ECT coefficients in the table are statistically significant and fall within the expected range. This suggests that there is a long-term equilibrium relationship between the variables in the model, and that the system tends to return to equilibrium quickly. For example, when ECT = 1, it indicates that 100% of the adjustment occurs within the period, meaning the adjustment is immediate and complete. When ECT = 0.5, it means 50% of the adjustment occurs each period. On the other hand, ECT = 0 implies no adjustment, making it nonsensical to claim a long-term relationship. In this case, the ECT is negative and highly significant (at the 99% confidence level or significance at the 0.01 level), indicating convergence. Thus, it can be concluded that in the ARDL bounds model, 10% of the adjustment from the short run to the long run occurs each period, meaning the adjustment takes place after 10 days in the ARDL model and after 7 days in the NARDL model. The ECT for the ARDL bounds model is -0.10, and for the NARDL model, it is -0.07. Both are statistically significant and fall within the accepted range of -1 and 0[6].

Furthermore, the F-Bounds statistics give an indication about the validity of the model. These statistics are used to determine model fit in the ARDL model. If the statistic from F-Bounds is significant, it indicates that there exists a cointegration relationship between variables in a long-term relation, thus confirming that in a long-term relationship there indeed exists a relationship in the variables under study in both the ARDL and NARDL models, which indicates that the chosen model is appropriate.

In other words, the bound test is used to determine if there is a long-term relationship. The null hypothesis states that there is no long-term relationship. Based on the F-statistics value, there are three possible scenarios:

1. If the F-statistic is lower than the I(0) value, we fail to reject the null hypothesis, indicating that there is no long-term relationship.
2. If the F-statistic is greater than the I(1) value, we reject the null hypothesis, suggesting there is a long-run relationship.
3. If the F-statistic falls between the two bounds, no conclusive evidence exists.

In our case, the F-Bounds statistic tests the null hypothesis of no co-integration ($\alpha_1 = 0$) in the linear ARDL models and $\alpha_1 = \alpha_2 = 0$ in the non-linear ARDL models. We fall in the second scenario where the F-statistic is greater than the upper bound, which implies that there exists a long-run relationship at 1% significance level.

As a result, the fact that the ECT coefficients are within the expected range and the F-Bounds statistics are statistically significant indicates the existence of long-term relationships and co-

[6] In some cases the accepted range can be between of -2 and 0

integration between the variables in the ARDL and NARDL models. This increases the reliability of the model and the ability to analyze long-term relationships of variables.

The χ^2_{Serial} statistic is a test statistic used to test serial dependence. Series dependence refers to the existence of a significant relationship between successive observations of a time series. If there is serial dependence in a time series, this can affect the reliability and predictive ability of the model. The χ^2_{Serial} statistic is a test statistic often used to test series dependence. This statistic is used to check the serial dependence between the error terms of the model.

If the χ^2_{Serial} statistic is not statistically significant, this indicates that there is no serial dependence between the error terms of the model. The χ^2_{Serial} statistics in the table show that serial dependence is not statistically significant in both models. This means that there is no obvious series dependence between the error terms of the ARDL and NARDL models used. Hence, this increases the reliability of the models and helps in accurately predicting the variables in the time series.

To interpret the coefficients, let's consider the effects of the variables in the given model:

C (Constant Coefficient) is the expected average change of NBP in the absence of independent variables. It was estimated as 0.79 in the ARDL (5,6) model. In the NARDL (12,11,11) model, it was estimated as 8.91. This represents the average change of NBP in the absence of influence of the independent variables.

JKM is the coefficient of the JKM variable that affects NBP. It was estimated as 0.717 in the ARDL (5,6) model. This indicates that increasing the JKM variable will increase NBP by 0.717 units. JKC^{pos} Shows the effect of positive JKM. It was estimated as 0.97 in the NARDL (12,11,11) model. This indicates that positive JKM events will increase NBP by 0.97 units. JKC^{neg} Shows the effect of negative JKM. It was estimated as 1.002 in the NARDL (12,11,11) model. This indicates that negative JKM events will increase NBP by 1.002 units. The significance of the coefficients is based on the t-values next to them. The "t" value indicates whether the coefficient is statistically significant. The * sign indicates that the coefficient is statistically significant at the 95% confidence level, while the *** sign indicates a stronger meaning (99%).

To summarize according to table A. NBP and JKM … are co-integrated and have long run relationship to each other. JKM has 0.71 impact on NBP. This effect are positive and statistically highly significant. The same results are concluded from NARDL model. While. According to NARDL model JKC^{POS} has 0.97 but JKC^{neg} coefficient is 1.002 that indicate negatives effect of JKM are more effective that positives JKM effects.

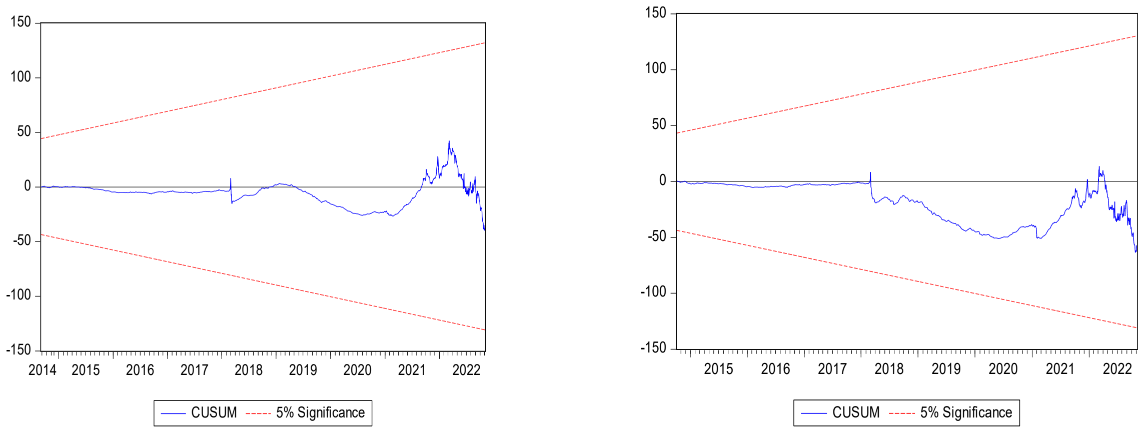

Figure 3. CUSUM

For diagnostics tests, stability and the accuracy of the estimated model are checked, firstly. For this goal, we employed cumulative sum (CUSUM) test. Figure of CUSUM confirms that the estimated models satisfy the stability condition, as there is no root lying outside the significance level. According to the CUSUM test results models in both cases (ARDL and NARDL) are stationary.

In the next step, we performed various tests to examine the serial correlation of the residuals. In this context, we applied the Lagrange Multiplier LM test, which is widely used to evaluate the serial correlation of the residuals. As a result of the application, we concluded that there was no serial correlation between the residuals. The χ^2_{Serial} value of the model shows the results of the Lagrange multiplier test for the serial correlation of the residuals at the 0.05% significance level. The null hypothesis of this test is that there is no serial correlation between the residuals. The test results show that the null hypothesis is accepted and therefore there is no relationship between the residuals. This finding provides an important indicator for the validity of our model. For clear understanding, we apply to dynamic multitier effect of JKM to NBP. In Figure 3 shows the results of dynamic multiplier effect.

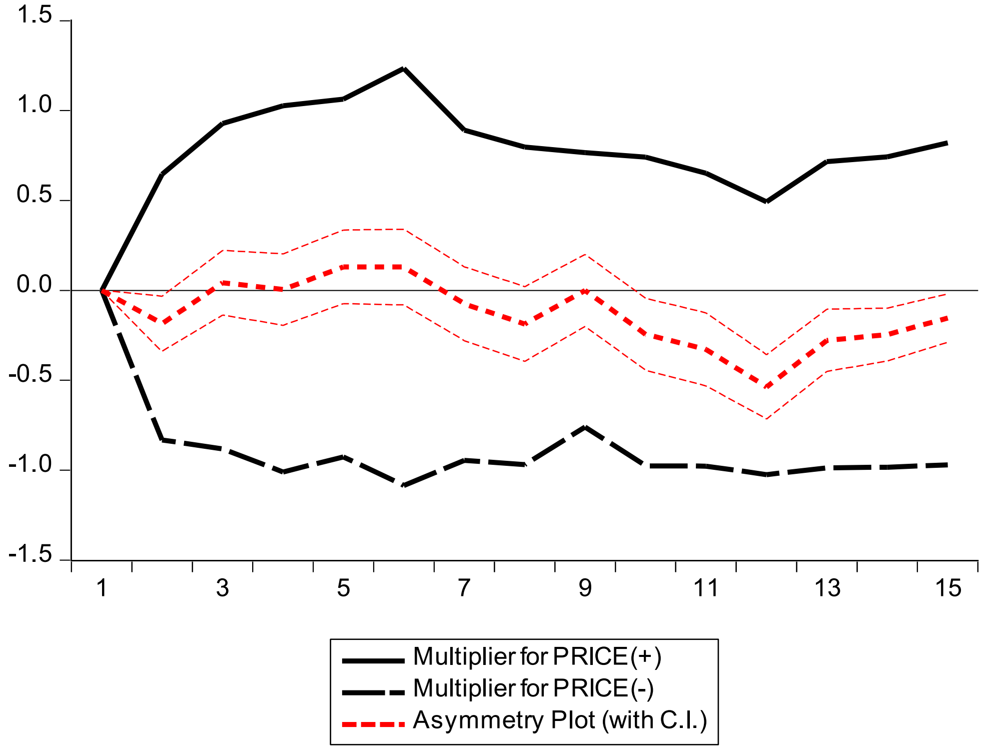

Figure 4. Multiplier Effects

The figure above shows the asymmetric effects between JKM and NBP prices and their dynamics over time. The “Multiplier for PRICE (+)” and “Multiplier for PRICE (-)” curves on the chart represent the effects of positive and negative price changes. “Asymmetry Plot (with C.I.)” enables the visualization of these asymmetric effects with confidence intervals. This analysis reveals the long-term relationship between JKM and NBP prices, as well as the asymmetric effects of price changes on the markets.

The results are confirmed results of NARDL model. As Graph show, after 10th periods negative effect become more effective than the positives, that make asymmetric plot to tend negative side in total.

4.2. Comparison of our Results with the Literature

This article examines the integration of European and East Asian natural gas markets and the mutual effects of price movements. Using the NARDL model, short- and long-term asymmetries were analyzed and the findings showed that both markets significantly influence each other. In particular, negative price movements have been found to have more impact than positive ones.

In the literature, various studies have addressed the integration of natural gas markets with different methods. For example, (Siliverstovs et al, 2005) stated that natural gas prices in Europe, North America and Japan move together, but there is no full integration globally. This is a result of geographical constraints and infrastructure deficiencies. The findings of this study also support this study by showing that there is a long-term relationship between European and East Asian markets. (Wilmot and Taivan, 2017) examined North American markets and found that market integration is asymmetric. That is, connections exist, but these connections are one-way. In this study, negative price movements are more effective highlights the asymmetric nature of interactions between markets. (Chuliá et al., 2019) pointed out the high integration of European and Asian markets, while North American markets differed. The findings of this study also show that there is a strong relationship between European and East Asian markets, but negative movements affect them more. (Łęt, 2017) examined the correlations between natural gas and oil markets in different regions and found a low level of integration between markets. As a result of this study analysis, negative price movements are more effective than positive ones, indicating that these low integration levels can increase the negative effects.

In conclusion, this study confirms the integration of European and East Asian natural gas markets and reveals that negative price movements have more pronounced effects, in line with other findings in the literature. This shows that market integration and price movements should be carefully evaluated when making energy policies and strategic decisions. This article makes significant contributions to the literature by highlighting the global integration in natural gas markets and the possible effects of this integration.

5. Conclusion

In this study, we examined how integrated the European and East Asian natural gas markets are with each other and how price movements in these markets affect each other. In our research, we analyzed the relationship between the behavior of natural gas prices using a nonlinear autoregressive distributed lag (NARDL) model. This model is one of the simplest methods to model short- and long-term asymmetries together and can be applied to stationary and non-stationary time series data.

In our study, we used daily East Asian natural gas spot prices (JKM) between 29 July 2014 and 17 November 2023 and daily UK National Balance Point (NBP) spot prices for the same period. Our analysis results revealed that the price movements of both markets significantly affect each other. In particular, we find that lagged price movements in one market have significant effects on prices in the other market.

According to our findings, we determined that negative price movements have larger impacts than positive movements. This shows that decreases in prices have more pronounced effects than increases. We also found that it takes approximately 9 to 12 months for long-term effects to appear. The effect of the JKM variable on NBP was estimated as 0.717 according to the ARDL (5,6) model. This means that a one unit increase in JKM will increase NBP prices by 0.717 units.

In our detailed analysis with the NARDL model, we found that the effect of positive JKM events on NBP was 0.97, and the effect of negative JKM events was 1.002. These results show that negative price movements are more effective than positive movements. Statistically, these effects were highly significant.

In conclusion, we determined that the European and East Asian natural gas markets are co-integrated and have a long-term relationship. The prices of both markets significantly influence each other, and this influence works both ways. In particular, we conclude that declines in the markets should be watched carefully, as the impact of negative price movements is greater. These findings demonstrate the global integration of natural gas markets and how changes in one region can affect other regions. Thus, we suggest that such international linkages should be taken into account when making energy policies and strategic decisions.

Future research on natural gas market dynamics can benefit from several key recommendations aimed at enhancing both the depth and scope of analysis.

First, expanding the geographical scope by incorporating other major natural gas markets beyond Europe and East Asia could provide a more comprehensive global understanding. For instance, analyzing the interlinkages between the North American or Middle Eastern gas markets and those of Europe and East Asia may reveal additional insights into global market integration.

While this study employed the NARDL model, future research could explore alternative nonlinear modeling techniques and other time series analysis methods. Comparing different methodological frameworks can improve the robustness and reliability of empirical findings, offering a richer interpretation of market behaviors. Moreover, macroeconomic factors such as exchange rates, oil prices, and geopolitical events play a crucial role in influencing natural gas prices. Investigating the indirect and spillover effects of these variables may reveal hidden channels through which they affect market integration and volatility. Another important consideration is the role of seasonal and cyclical factors in shaping natural gas demand and prices. A detailed analysis of these patterns can improve forecasting accuracy and enhance the precision of market predictions, particularly during peak consumption periods such as winter.

The impact of policies and regulatory frameworks across different regions should also be examined. Understanding how government interventions and energy regulations influence natural gas markets can inform policy-making and promote harmonization across borders for more efficient market functioning. Additionally, conducting long-term forecasts and scenario analyses could provide insights into the future of natural gas markets under different conditions. In particular, the growing adoption of renewable energy sources may significantly alter the structure and demand dynamics of natural gas markets. Improving the quality and timeliness of datasets used in empirical studies is another essential area. Access to larger, more detailed, and up-to-date data can greatly enhance the accuracy of statistical models and improve the reliability of results.

Lastly, adopting interdisciplinary approaches by integrating perspectives from economics, energy engineering, and environmental sciences can foster a more holistic understanding of natural gas markets. Such collaboration would enrich the analytical framework and contribute to more informed strategic decision-making.

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