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What can be learned from the free destination option in the LNG *imbroglio*?

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Abstract

We examine the profitability of flexible routing by LNG cargoes for a single supplier taking into account uncertainty in the medium-term dynamics of gas markets. First, we model the trajectory of natural gas prices in Asia, Northern America, and Europe using a Threshold Vector AutoRegression representation (TVAR) in which the system's dynamics switches back and forth between high and low regimes of oil price volatility. We then use the generalized impulse response functions (GIRF) obtained from the estimated threshold model to analyze the effects of volatility shocks on the regional gas markets dynamics. Lastly, the valuation of destination flexibility in LNG supplies is conducted using a real option approach. We generate a sample of possible future regional price trajectories using Monte Carlo simulations of our empirical model and determine for each trajectory the optimal shipping decisions and their profitability. Our results portend a substantial source of profit for the industry and reveal future movements of vessels. We discuss the conditional impact of destination flexibility on the globalization of natural gas markets.

Keywords: LNG arbitrage, destination flexibility option, volatility, TVAR, Monte Carlo simulation

1. Introduction

The 21st century imperative of flexibility has not spared the liquefied natural gas (LNG) industry. Reaching a historic high in 2016 with 258 million tons (Mt) of traded LNG volumes (IGU, 2017), global LNG trade is set to be fostered by projections of strong growth of global gas supplies mainly driven by the US shale advent and the arrival of new liquefaction capacities from Australia. In terms of additional capacities, the emergence of new actors not only has a major impact but it also provides a key contribution to flexible contracted volumes. With fundamentally different business models, volumes made available by US projects are sold free on board (FOB) and include pricing formulas that rely on hub-indexation. The growing flexibility wisdom is part of a more generalized movement that has led to an increase of spot and short-term LNG trade and

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fewer long-term binding contracts with decreased duration, relaxed inflexible clauses (e.g., take-or-pay obligations), fewer destination contraints[2] and an increasing reliance to hub-indexation allowing for gas-to-gas competition (Ruester, 2009; Hartley, 2015).[3]

However, this shift remains progressive. A transition period with new contracts that still includes destination clauses, oil indexation pricing formulas and limited reliance on spot trade is expected on the medium-term horizon (IEA/OECD, 2016). This transitional phase primarily involves Asia as the focal point of action in the coming years. The common prospect in the LNG industry foresees that it will take five to 10 years to see LNG imports markets complete their liberalization process and establish a hub with sufficient liquidity to build a credible reference price for Asian LNG trade.

Meanwhile, flexibility in LNG markets, as a good metric of the current market evolutions, will stem from contracts themselves in the coming years. Yet market flexibility could come from uncontracted LNG supplies, portfolio players[4] and diverted LNG supplies. However, only the third option effectively provides flexibility.[5]

Our paper aims at putting contract flexibility into the perspective of medium-term market evolution based on market forecast. To determine the value of destination flexibility in LNG contracts, we follow and extend the real option approach proposed by Yepes Rodríguez (2008) by evaluating the profitability of flexible routing of LNG cargoes for a single supplier according to the degree of uncertainty in the market. That methodology can be decomposed into two successive steps. First, one has to examine and model the intricate dynamic interdependences among the prices of natural gas observed in the three main consuming regions (Japan, Europe, and United States). Then, Monte Carlo simulations of the obtained empirical model are conducted to generate a sample of future price trajectories that are consistent with the observed price dynamics. These trajectories are in turn used to determine the optimal LNG shipping decisions and their profitabilities.

From an empirical perspective, the modeling strategy retained in the present paper considers the possibly non-linear nature of the dynamic interdependences among these prices to meet the following three requirements. The first is to exploit the inter-relationships between the three markets by moving beyond of the generally used linear cointegrating framework as in Neumann (2009), Brown and Yücel (2008) and Kao and Wan (2009). In this vein, Siliverstovs et al. (2005) analyzed the relationship between international natural gas market prices through principal components analysis and Johansen likelihood-based cointegration procedure.[6] Their most important result is that the natural gas markets accross the Atlantic were not integrated with limited opportunities for arbitrage between either side of the Atlantic. This finding implies that the contractual

[2] The US shale gas revolution and the aftermath of the Fukushima disaster in 2011 have exacerbated regional price differentials, further encouraging buyers to re-sell/divert LNG cargoes to third-party destinations.

[3] Among the market developments that have prominently contributed to this reconfiguration, the waves of market liberalization, the end of destination clauses in Europe, the substantial increase in the number of buyers, third-party access to regasification terminals, the large growth of LNG fleet and the regional gas price differentials post-2010 have been crucial.

[4] They aggregate supplies from diverse projects and re-sell to different customers.

[5] Indeed, concerning portfolio players, their impact in terms of flexibility has been found to be ambiguous as the flexible LNG purchased tend to be sold to customers with oil-indexed LNG contracts (Rogers, 2017). As for the uncontracted LNG supplies, limited volumes are expected to come on stream over the next few years meaning that the extent to which LNG production would be able to respond to a potential demand shock is very limited (IEA/OECD, 2016).

[6] Both of them show a high level of natural gas market integration within Europe, between the European and Japanese markets as well as within the North American market.

structures and the dynamics of fundamentals remained intrinsically different.[7] The second is to consider the presence of nonlinearities: linear models may not correctly capture transaction costs, market power (Ritz, 2014), asymmetry of the economic cycle, extreme events, regulations and inherent rigidity in the market. All these factors may cause non-linear effects such as unexpected changes, structural breaks or asymmetric responses to news.[8] Thirdly, we need to recognize the uncertainties that may affect the dynamics of natural gas markets. The current context especially highlights the uncertainty weighing on the Asian demand,7 the extent to which Europe will maintain its role of balancing the market and on the pace at which the transition to market- related pricing mechanisms will take place, particularly in Asia, to replace oil indexation pricing in long-term contracts.

Our paper breaks new ground by estimating a threshold vector autoregressive model (TVAR) in a similar approach to that of Balke (2000), in which oil price volatility[9] plays the role of non-linear propagator of shocks in the regional LNG markets. The Threshold VAR model combined with nonlinear impulse response functions has a number of interesting features that make it attractive for our purpose. First, a TVAR model provides a fairly simple way to capture non-linear dynamics such as asymmetric responses to shocks, regime-switching and multiple equilibriums. Moreover, the variable by which different regimes are defined can itself be endogenous and included in the VAR.[10] More interestingly, the impulse response functions are no longer linear as they depend on the sign and the size of the shock but also on initial conditions; they are derived as conditional forecasts at each period of time. Therefore, it becomes possible to analyze time-variance in responses to shocks not only across regimes, but also within regimes.[11] Finally, the TVAR allows us to exploit the oil-gas relationship as the system switches back and forth between high and low regimes of oil price volatility in response to shocks to other variables. The use of that variable is supported by several practices: the persisting use of oil-indexed price formulas in long-term LNG contracts over the medium-term horizon, especially for the major importer (Japan); the behavior of portfolio players that will substantially anchor the oil price dynamics to that of the natural gas in contracts with short-term expiration dates;[12] and the well-recognized linkage of oil price fluctuations with uncertainties about the global economic activity.

We then generate Monte Carlo simulations of the future price series and the subsequent shipping decisions to get the distribution of values for the option of diverting cargoes. The mean value over 10,000 possible future price trajectories in the three alternative destination markets is considered in each scenario. By taking into account the freight route costs, we have considered

[7] The rise in Henry Hub prices in the early 2000s has triggered the construction of major regasification terminals that the shale gas revolution finally converted into liquefaction units. On the other side of the Atlantic, Europe has experienced a gradual decoupling of natural gas prices from those of oil since 2009 in a context of limited regasification capacities across the region. Compared to the US and European gas markets that are mainly supplied by local producers or pipeline imports, Japan is highly dependent on LNG imports. In this market, the Fukushima disaster in 2011 brought a turning point inthe LNG price dynamics.

[8] Creamer and Creamer (2014) applied Brownian Distance Correlation tests for non-linearity to one-month forward futures of natural gas from the NYMEX and found significant non-linear relationships. This is also confirmed by Matilla-García et al. (2007) based on the generalized Brock-Dechert-Scheinkman and Kaplan's test.

[9] Measured as the sample standard deviation of adjusted log price changes by using WTI spot prices.

[10] This is not the case within the framework of Markov-switching models where regime shifts evolve according to a Markov chain with a state variable not directly observable, or nonlinear logistic smooth transition VAR models where regime changes are determined by the asymmetric and dynamic interactions of all the variables.

[11] This feature makes a threshold VAR a convenient alternative to time-varying parameter (TVP)-VAR that imposes a priori structure and will allow us to analyze the impact of shocks according to different regimes of oil price volatility in the European, Japanese, and US markets.

[12] They tend to buy gas-indexed volumes and resell with oil-indexed formulas (IEA/OECD, 2016).

several configurations of an LNG supplier based either in Australia, Africa, the Middle-East, or North America. A base case where the supplier is committed to send its LNG cargoes to a unique destination (Europe, Japan or North America) is compared to a free destination case where LNG could be flowed to one of three alternative markets to maximize the profits obtained from the sale of that cargo on a monthly basis.

Results have generally highlighted a significant value of the flexibility option. Moreover, the option of free destination has been found to be substantially larger in the high case scenario suggesting that the more the market, particularly in Asia, swiftly repositions to a more flexible reconfiguration, ultimately involving the dissolution of destination clauses and the use of a hub-pricing in contractual terms, the more the players of this industry will be inclined to commit and take advantage of arbitrage opportunities. In this respect, our results are in perfect agreement with those of Shi and Variam (2016) that call for a prioritization of the destination issue over oil-indexation in East Asia .

This paper fits into a relatively large research area that considers the impact of the LNG market reconfiguration on the contractual practices (Von Hirschhausen and Neumann, 2008; Ruester, 2009; Hartley, 2015) and the consequences on the issue of regional NG market integration (Siliverstovs et al., 2005; Neumann, 2009). Recent studies focus on East Asian markets efforts in creating hubs and changing contract terms toward a removal of destination clauses and the adoption of hub indexation (Shi and Variam, 2016). The debate over whether the Asian premium in NG trade is due to price discrimination or market fundamentals is also considered (Zhang et al., 2018). Concerning the specific question of destination restriction in long term LNG contracts, YepesRodríguez (2008) is the only study that exclusively focuses on this issue. Our paper enriches this literature as no existing study re-examined this issue by taking into account recent developments in the LNG market and the uncertainties that may affect its dynamics.

We extend Yepes Rodríguez (2008) in several ways. First, instead of describing the evolution of NG prices with Brownian motions which have the drawback of moving far away from their initial point, we rather consider a threshold modeling strategy based on a non-linear econometric approach (Balke, 2000). To the best of our knowledge, this is the first modeling analysis that takes into account the role of oil price volatility as a non-linear propagator of shocks to provide a new understanding of the link between regional natural gas price references. It hence fills the gap in the literature about gas market integration as the issue has been neglected since 2010[13] and also the one related to the more complex evolving relationship between oil and gas markets. Secondly, our model allows the value of the free destination option to be associated to a level of uncertainty in the market: these scenarios expand the scope of the valued option to the increasingly complex outlook of LNG. This is an other line of improvement regarding the hypothesis of constant prices volatility assumed in the Yepes Rodríguez (2008) approach as regional prices dynamics in our model switch back and forth between a high and low regime of oil price volatility. Thirdly, we have assumed the possibility to benefit from arbitrage opportunities on a monthly basis as a way to strengthen Yepes Rodríguez (2008) results that have suggested an important share of the destination flexibility option in the LNG value chain on a yearly basis. Finally, by taking into account spatial considerations, we have extended the calculation of the flexibility option to suppliers based in five countries and have estimated the profitability from diverting their cargoes to an alternative market.

[13]To the best of our knowledge, there has been are no econometric study on the degree of integration of intercontinental gas markets since 2011.

Our results have useful implications. First, from the industry standpoint, not only the shortfall for a producer who would be constrained in terms of destination by a long-term contract could be conveyed by the destination option but also the important source of value for profit motive actors who are in a position to arbitrage. In this respect, the recent arrival of trading houses in this market would be prominent in terms of flexibility and market diversification; and the present work should help to understand how to value and manage these participants' businesses. Secondly, at the heart of the vivid debate over the potential integration of regional markets, this paper shows that the contractual aspect of this industry is capable of constituting a serious barrier in global LNG trade. The required cautious interpretation of the impact of the destination option on natural gas price convergence debate has been discussed. We conclude that expecting an integration of NG markets only via the effect of appropriation of best netbacks when suppliers can choose their ultimate market destination is misleading. The shortfall of geographically constrained producers rather highlights the benefits of greater future spot market reliance as even partners engaged in long-term contracts could profit from a participation in the spot market, thus increasing the liquidity of the latter. If it works in tandem with a lower indexation of oil prices and the market forces driving movements of vessels then, in this exact case, one would expect a possible "convergence". Finally, from a security of supply standpoint, with relatively low physical flexibility from the LNG export infrastructure and high utilization of liquefaction plants that tend to be base load (IEA/OECD, 2016), making it possible for the contracting parties to supply additional LNG or shifting the destination of LNG delivery, would play a pivotal role in terms of the resiliency to unforeseen events. From this perspective and in view of the steadfast need to manage gas demand uncertainty, the value of destination flexibility far outweighs the optional value calculated in this paper compared to the possible consequences of an unforeseen shock.

The remainder of the paper is organized as follows. The next section presents a brief overview of the existing theoretical and empirical studies surrounding the contractual aspect of the LNG industry and the question of destination flexibility. Sections 3 and 4 describe the real option model for the valuation of destination flexibility option and the model underlying LNG prices forecasts. Sections 5 and 6 present the results. Sections 7 and 8 discuss and conclude the paper.

2. Background

In the following, we present an overview of the contractual aspects of the natural gas industry and the issue of destination clauses that we contextualize in the new LNG market environment.

2.1. Long-term commitments and LNG trade

The pivotal question of destination flexibility is above all a matter of contract. Long-term commitments have always been an inherent component of the LNG business and the economics literature has extensively grasped the issue by flaunting the merits of these contractual imperatives on the one hand and analyzing their impact on NG trade on the other. Williamson (1979)'s seminal work helps us to understand the irrepressible need for long-term contracts via transaction costs economic theory. The durable transaction-specific and infrastructure-related nature of NG investments not only call for long-term contracts to support high investment costs but it also exposes the parties to hold-up risk. More specifically, it assumes the possibility of ex-post opportunistic behavior and strategic bargaining by the trading partners that suggest we move beyond the picture of an impersonal market and perceive the idiosyncrasy of contractual relations. Klein et al. (1978) described it as “appropriable quasi rents” that substantially explain decisions to vertically integrate. Entering into long-term contracts is then seen as an efficient tool to minimize transaction costs in view of the limited rationality of the players adding the issue of asymmetric information. Masten (1998)’s study refers to several works that aimed at analyzing contracts duration and design. Pirrong (1993) concludes that long-term arrangements prevail in specialized markets and reputation and repeat transactions are not enough to prevent strategic behavior without formal commitments. In this respect, the capital intensity of infrastructures in the gas industry has paved the way for several analyses on the sector from both a theoretical and an empirical point of view (see, among others, Gray (1978), Hubbard and Weiner (1986), Crocker and Masten (1988) and Klein et al. (1990)). Creti and Villeneuve (2004) provide empirical and theoretical insights on long term contracts by examining the role of take-or-pay clauses and price indexation and opening up the discussion on the impact of regulation in the optimal contract duration. In Neuhoff and von Hirschhausen (2006), they studied the role of long-term contracts under the liberalization point of view. In the same vein, Von Hirschhausen and Neumann (2008) focused on factors affecting the duration of contracts by examining 311 long-term contracts between natural gas producers and consumers between 1964 and 2006. Contract duration is found to be shorter for deliveries in the US and UK markets and contracts related to investment in specific projects are of longer duration (see Ruester (2009)). Massol and Tchung-Ming (2010) underline that these rigid contractual structures result in a cost-inefficient organization of LNG shipping that could be rationalized.

Price convergence within regional markets has also been studied (Serletis, 1997; Walls, 1994 and Neumann et al., 2006). Few researches have investigated the potential integration of gas markets from a global perspective. Siliverstovs et al. (2005) obtain mixed results from a cointegration technique with evidence of market integration between European and Japanese markets but no integration between North America and Japan. Over the period 1999 to 2008, Neumann (2009) finds increased convergence of gas spot prices between North America and Europe and Barnes and Bosworth (2015)’s results suggests that the international NG market is less regional overall due to increased trade in LNG via a gravity model.

2.2. *Destination flexibility*

The archetypal contractual scheme used in the LNG industry is that of a producer that contracts either the entire output or a substantial portion of the output of a liquefaction plant to buyers for an average of 25 years or more for a price indexed to crude oil. In most cases, buyers are mid-stream utilities that sell gas and electricity to end customers. A typical contract also includes the so-called "take or pay" clauses according to which the seller guarantees the gas will be made available to the buyer, who in return guarantees the payment of a minimum quantity of energy, that he takes delivery or not. For a long time, price indexation was done with geographical variations: the price of gas was fixed according to the prices of competing energies on each market considered. These "netback" clauses could be applied only if the gas was indeed sold on the market for which it was intended.[14] This clause excluded any possibility of resale of contracted gas to supply in adjacent markets. There was therefore no opportunity for trade between distributors in different countries, nor for trade-offs between the different national markets. Security of supply and investment has been claimed as reasonable reasons to introduce these traditional

[14] More specifically, final destination clause made it possible to base the formula for calculating the price in "netback".

“dedicated contracts” with a predefined destination of the cargoes (Glachant and Hallack, 2009) even if it clearly constitutes a roadblock to a "gas-to-gas competition".

Nevertheless, even when long-term contracts do not entail destination restrictions, the incoterms may be such as to hinder market flexibility. In this respect, the Delivered Ex Ship (DES) contracts require that the gas exchange takes place at the port of destination and that any redirection of LNG cargoes prior to arrival at the agreed port requires some negotiation between buyers and sellers. On the other hand, Free on Board (FOB) contracts suggest that the exchange of LNG is done at the port of loading thus leaving more room for maneuver to divert the cargoes from their original destination.[15] When FOB deliveries are concerned, “destination flexibility” actually refers to the fact of being able to divert a shipment of LNG according to its original destination; for a DES contract, one speaks about “right of diversion” to designate this phenomenon (Corbeau and Ledesma, 2016). Beyond these contractual considerations, buyers under the aegis of a long-term contract may come to demand the diversion of their cargo to an alternative market for operational reasons such as technical issues, insufficient demand, limited storage capacity at unloading terminals or force majeure. These so-called “cargo swaps” represent only a tiny fraction of the LNG trade and are often seen as an effective means of reducing navigation distances when both counterparts are able to receive LNG in two different destinations.[16]

When it comes to commercial reasons underpinning the diversion decision, the contractual landscape becomes complex. As highlighted by the survey on LNG trades by the Japan Fair Trade Commission (2017), there are some contracts providing that diversion “shall not be due to buyer’s commercial reasons” or “diversion is not for resale to seller’s other customers” or that “diversion shall be due to only seller’s direct sales to a third party, who owns or manages an unloading terminal”.

2.3. *LNG markets’ growing flexibility*

Recent developments have led to a deep reconfiguration of the contractual structure governing the LNG trade. The waves of market liberalization, third-party access to regasification infrastructures, the substantial increase of the fleet of LNG vessels and the rise in the number of buyers have been crucial (Corbeau and Ledesma, 2016). The American shale gas revolution combined with strong Asian demand in the aftermath of the Fukushima disaster in 2011 have exacerbated regional price differentials, further encouraging diversion decisions. In this context, long-term contracts experienced fundamental changes in comparison with their former structure : the contract duration substantially decreased and hub pricing is increasingly replacing oil-indexed prices (Hartley, 2015).[17]. Asia is still experiencing a transition period toward more flexible market structure. Indeed, LNG volumes imported by Asia were only flexible at 5% in 2016 (IEA/OECD, 2016) and the common prospect among the LNG industry foresees that it will take five to ten years to see LNG import markets complete their liberalization processes and establish a hub with sufficient liquidity to build a credible reference price for Asian LNG trade. In the meantime, Asian buyers are showing their support for a change in oil price indexation for

[15]In the DES contracts, the seller is responsible for the delivery of LNG and assumes the costs of transport and insurance contrary to FOB contracts where the buyer must bear these costs.

[16]Additional costs must be taken into account in the event of a diversion decision: transport costs, port charges, insurance fees, additional costs of the replaced LNG in the initial market and regasification fees in the alternative market.

[17]This result is also related to the elimination of destination clauses in European contracts that were found to be anticompetitive by the European Commission in 2011. Such restrictions were considered as price discrimination by maintaining the seller’s prices in different markets.

new long-term contracts.[18] Shi and Variam (2016) examined the potential impact of East Asia's efforts in creating hubs and changing contract terms toward a removal of destination clauses and the adoption of hub indexation. Using the Nexant World Gas Model, their findings suggest that the removal of the destination clause in long-term LNG contracts should be the priority over indexation issues for two reasons. First, this does not imply liberalizing the market, which can be very costly in terms of time. Secondly, importing countries have all the sovereignty to forbid firms to sign contracts with oil indexation (Cogan Jr, 2006).

Against this background, the persistent need to resort to long-term contracts in the LNG industry leaves open the issue of destination flexibility that remains unresolved in Asian markets. The transition period toward a more flexible repositioning independent of oil indexation needs time to be completed and is accompanied by strong uncertainties over the medium-term horizon of the LNG market. To take this into account, we have adopted the only approach that has gave an economic value to the diverting option in the LNG market (Yepes Rodríguez, 2008) [19] by connecting a real option approach to two literature strands: one on the integration of regional NG markets where little research has been investigated since the post-2010 gas price differentials[20] and the other one on the persistent influence of oil prices on the dynamics of the gas markets (section 4.3.1 explains in detail the transmission mechanisms at play).

3. Real option model for the valuation of the free destination

We develop a model to evaluate the opportunity of flexible routing of LNG cargoes for a single supplier. Our approach can be decomposed into three successive steps. First, we model the interactions among the price series observed in the three main importing regions using a threshold VAR specification. In a second step, we use that empirical model to conduct a series of Monte Carlo simulations aimed at generating a large number (10,000) of future price trajectories over a 36-month horizon. By construction, these trajectories are consistent with the observed dynamics. Third, we evaluate, for each of these trajectories, the stream of future net revenues obtained by an LNG exporter under two cases depending on whether the destination of its shipments is kept fixed or flexible.

By construction, the net present value of the exporter's stream of future revenue depends on the location of the exporter's liquefaction plant. Hence, we successively consider several possible locations in Oceania (Australia), Middle-East (Qatar), North America (USA - Atlantic), North Africa (Algeria), West Africa (Nigeria) where the LNG is committed to a unique destination (Europe, Japan or North America) as a base case (hereafter, labeled reference case). We will then compare it to the free destination case where LNG can flow to one of the three alternative markets to maximize the profits obtained from the sale of that cargo. Depending on the location of the supplier and its alternative destinations, the extra transportation costs would reflect, among others, the fuel oil cost, the vessel charter rate, the ship size, the trip length, and other fundamental elements of the full-blown shipping market. Benefiting from an arbitrage opportunity will then occur in those months in which the price differentials between the initial and alternative

[18] The share of oil indexed contracted LNG and pipeline gas in East Asia was 88% higher than the global average of 65% (IGU, 2016).

[19] Results suggested that the free destination option is highly likely to improve the value of long-term LNG supplies by between 6% and 43% .

[20] International price correlations should have declined compared to the mid/late 2000s with the Fukushima accident representing a structural break.

market destination would be large enough to counterbalance the incremental shipping costs of diversion.[21] Following Yepes Rodríguez (2008), the value of a destination flexibility option for a unit production capacity in a given month m:

$$v(m) = Max(p_{alternative}(m) - p_{reference}(m) - \triangle t(m); 0) \tag{1}$$

with $p_{alternative}$: the average price of LNG in a future month m in the three possible alternative markets (Europe, Japan, and the US) and $p_{reference}$ the average price of LNG in the initial market in a future month m.

The value $v(m)$ has to be compared with the value of LNG supply without destination flexibility:

$$\bar{v}(m) = max(p_{reference}(m) - t_{reference}(m); 0) \tag{2}$$

The results of each scenario are presented in terms of the monthly average unit of $v(m)$ for a supply period T of 36 months. We let V denote the average value of destination flexibility for this medium-term period for a unit production capacity as the discounted sum of $v(m)$ over the supply period of T months:

$$V = \frac{\sum_{m=1}^{T} v(m).\delta^m}{\sum_{m=1}^{T} \delta^m} \tag{3}$$

where δ the risk-free discount factor.[22] The value V is compared to $\bar{V}$ the average unit value obtained in case of a project with an inflexible shipping policy:

$$\bar{V} = \frac{\sum_{m=1}^{T} \bar{v}(m).\delta^m}{\sum_{m=1}^{T} \delta^m} \tag{4}$$

4. Empirical strategy

4.1. Data

The data consists of monthly prices of NG for the three major gas-consuming regions worldwide, namely Continental Europe, Japan, and the US. Henry Hub natural gas spot price, Japan LNG import price from Indonesia and Russian natural gas border prices in Germany are used to proxy the LNG price in US, Japan, and Europe. These prices were collected from January 1992 to June 2017. Data has been gathered from the IMF Primary Commodity prices. The prices are denominated in US$ /MMBtu. The model also includes a measure of oil price volatility calculated from the weekly spot prices of WTI. Given the purpose of the study, we opted for a monthly

[21]The additional costs arising from diversion include: honoring the LNG volumes initially granted to the original destination market, access fees to regasification terminals in the alternative market and extra maritime costs.

[22]We assume a discount factor δ of 0,99 as a reasonable risk-free discount factor when considering a long-term supply period, T, of 25 years. As emphasized by Yepes Rodríguez (2008), a lower value δ would affect the calculation of the value of the free destination option as it will give more weight to the first years of the supply period and hence increasing the sensitivity of the results to the initial market prices. .

frequency of the data with the aim of exploiting the possibility of monthly arbitrage opportunities between the three regions upon which the destination flexibility option will be based, which is a reasonable assumption with regard to shipping considerations.

A preliminary overview of the data in Figure 1 shows a reaction of markets to major exceptional events, e.g., the Californian crisis of 2000, the upward trend in natural gas prices following the soaring oil prices in the 2000s, the global financial crisis of 2007-2008 or the Fukushima disaster in 2011. The global picture underlying the price dynamics displays the following main facts: the rise in Henry Hub prices in the early 2000s (spiking in 2005 and 2008) that triggered the construction of major regasification terminals that the shale gas revolution finally converted into liquefaction units. Besides, on the other side of the Atlantic, Europe has experienced a gradual decoupling of natural gas prices from those of oil since 2009 in a context of limited regasification capacities across the region. Compared with the US and European gas markets that are mainly supplied by local producers or pipeline imports, Japan is highly dependent on LNG imports. In this context, the Fukushima disaster in 2011 brought about a turning point of the LNG price dynamics. The following period of a tight market pushed LNG prices in long-term contracts to be completely guided by oil prices. The subsequent rise was also felt in Asian spot prices which are linked to the Japanese oil-indexed average price. The resulted regional price differentials enhanced the incentive to redirect LNG cargoes initially destined for Europe as the latter had the ability to rely on pipeline gas imports. Finally, the drop in oil prices in 2014 marked the end of the « boundless Asian premium », leading to a new LNG environment affected by the strong growth in global gas supply.[23]

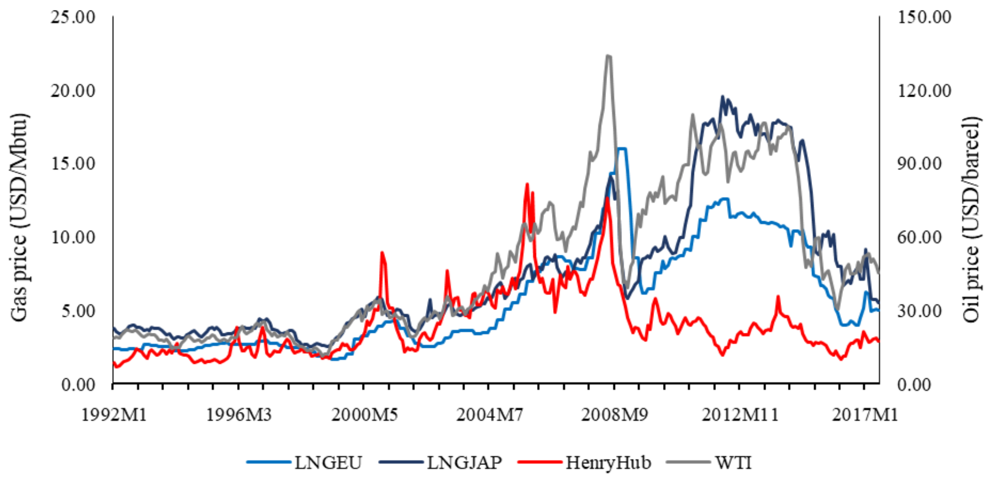

Figure 1: Natural gas import prices from the three main consuming regions and WTI crude oil price

[23]Driven by the US shale gas revolution and the arrival of new liquefaction capacities from Australia and other regions all over the world.

4.2. Preliminary analysis of time series

Table 4.2 reports some descriptive statistics of the prices in first-logarithmic difference. The skewness and kurtosis coefficients indicate a non-normal distribution for all prices with a higher probability of extreme values. The highly likely occurrence of extreme values and the asymmetric nature of distributions calls for a non-linear specification. The Jarque-Bera (1980) statistics confirmed the non-normality at the 5% and 1% level. To check the stationarity properties of the series, we used Perron (1989), Augmented Dickey-Fuller (1979) and Philipps-Perron (1988) tests. The series are all integrated of order 1 according to all test results. In the sequel, all variables are transformed into their first-logarithmic difference form.

	Natural gas			*Oil*
	US	Europe	Japan	WTI
Descriptive statistics				
Observations	305	305	305	305
Mean	0.002	0.002	0.001	0.002
Median	-0.001	0.000	50.008	0.011
Maximum	0.479	0.405	0.258	0.214
Minimum	-0.429	-0.288	-0.368	-0.331
Std. Dev.	0.133	0.063	0.068	50.082
Skewness	0.057	0.281	-1.057	-0.657
Kurtosis	3.930	11.695	7.746	4.484
Jarque-Bera	11.178	964.806	342.997	49.937
Probability	0.003	0.000	0.000	0.000

Table 1: Descriptive statistics of the prices in first-logarithmic difference.

4.3. Testing and Estimation of the TVAR model

The Threshold Vector Autoregression (TVAR) approach[24] used in this paper is similar to that of Balke (2000) who examined whether credit conditions act as a non-linear shock propagator. This propagation takes the form of regime change when credit conditions cross a critical threshold.

The TVAR model combined with nonlinear impulse response functions has a number of interesting features that make it attractive for our purpose. First, a TVAR model provides a fairly simple way to capture non-linear dynamics such as asymmetric responses to shocks, regime-switching and multiple equilibriums. Moreover, the variable by which different regimes are defined can itself be endogenous and included in the VAR.[25] More interestingly, the impulse response functions are no longer linear as they depend on the sign and the size of the shock but also on initial conditions; they are derived as conditional forecasts at each period of time. Therefore, it becomes possible to analyze time-variance in responses to shocks not only across

[24] See Tong (1990) for the general structure of non-linear autoregressive models.

[25] This is not the case within the framework of Markov-switching models where regime shifts evolve according to a Markov chain with a state variable not directly observable, or nonlinear logistic smooth transition VAR models where regime changes are determined by the asymmetric and dynamic interactions of all the variables.

regimes, but also within regimes.[26] Finally, the TVAR allows us to exploit the oil-gas relationship as the system switches back and forth between high and low regimes of oil price volatility in response to shocks to other variables.[27]

Threshold vector autoregression model can be specified as follows:

$$Y_t = A^1 Y_t + \; B^1(L)Y_{t-1} + (A^2 Y_t + B^2(L)Y_{t-1})I[s_{t-d} > \gamma] + U_t \tag{5}$$

where Y_t is a vector containing the endogenous stationary variables namely the logged first-difference of Japan LNG prices, Europe LNG prices, US Henry Hub, and a measure of oil price volatility. s_{t-d} is the threshold variable that determines the volatility regime that prevails in the system[28] and I is an indicator function that takes the value one when the transition variable exceeds the threshold value γ and 0 otherwise. $B^1(L)$ and $B^2(L)$ are lag polynomial matrices and U_t is the vector of orthogonalized error terms. Shocks to the three regional LNG prices and also to the volatility variable will identify whether the market is in a regime of high volatility. A^1 and A^2 represent the contemporaneous relationships in both regimes of volatility[29] and are supposed to have a recursive structure with the causal ordering of US LNG prices, Japan LNG prices, European NG prices and the variable of uncertainty conditions;[30] implying that the volatility variable would respond contemporaneously to all variables in the system.

When estimating TVAR models, we are confronted with the endogeneity issue as the threshold variable is allowed to endogenously respond to natural gas price shocks. To overcome this issue, the common approach is to consider that the threshold variable switches accross regimes with a delay. Also, the TVAR literature suggests defining the threshold variable as a moving average process needing some persistence in the variation of the threshold variable before shocks cause regime switching. Altogether, to thoroughly address the endogeneity issue, we have combined these two approaches by considering a three-period moving average of the two-month-lagged threshold variable. Robustness checks have shown that results are robust to different lag specifications.

An important question is whether the estimated TVAR model is statistically significant relative to a linear VAR. As the threshold value is unknown and needs to be estimated, the threshold model is estimated by least squares for all possible thresholds values. For each possible value of the threshold, we test the hypothesis that the coefficients of the model are equal across regimes, that is $A^2 = B^2(\mathrm{L}) = 0$, by using a multivariate extension of the linearity test by Hansen (1999) and Lo and Zivot (2001).

Before testing for a threshold effect in the vector autoregression representation of the data, we estimate a linear VAR in order to select the optimal lag order that has been set to three in compliance with Akaike (AIC) and Hannan-Quinn (HQ) information criterions.[31]

[26] This feature makes a threshold VAR a convenient alternative to time-varying parameter (TVP)-VAR that imposes a priori structure and will allow us to analyze the impact of shocks according to different regimes of oil price volatility in the European, Japanese, and US markets.

[27] The model is estimated using WinRATS and the dedicated estimation procedure provided by Nathan Balke.

[28] By being an element of Y_t, the threshold autoregressive model hence reflects both the evolution of Y_t and the volatility regimes.

[29] Which are also likely to vary according to the volatility regime considered (idem for the lag polynomials).

[30] The choice of a threshold structure is not affected by other orderings.

[31] For all variables except the volatility measure, we have used the first difference of natural logarithm tranformation.

4.3.1. Choice of the transition variable

To better grasp the price dynamics that lay ahead in the LNG markets, we have chosen to consider volatility scenarios by exploiting the oil-gas relationship. More specifically, we have retained the oil price volatility,[32] found to be a significant predictor of natural gas returns (Pindyck, 2004), as a non-linear propagator of shocks in the LNG markets. A plethora of elements may explain this choice:

First, if oil price volatility matters when looking at the future of LNG markets, this could be explained by the historic relationship between the two commodities. In this regard, Serletis and Herbert (1999) and Brown and Yücel (2008) find that crude oil or refined products and US gas prices exhibit a high correlation and are cointegrated. Villar and Joutz (2006) results suggest the existence of a long-run relationship in which the price of WTI is weakly exogenous to the price of natural gas at the Henry Hub; meaning that the price of natural gas adjusts to deviations in the long-run evolving relationship but these deviations do not affect the oil price. Substitution and competition are not the only driving forces of such a trend. Legislations or technological changes have also been found to be crucial (Hartley et al., 2007).

The energy industry has long tried to relate natural gas prices to those of oil via rules of thumb (Brown and Yücel, 2008), but the failure of these rules to explain differential trajectories of oil and natural gas prices in long periods has contributed to the emerging idea of a decoupling of natural gas from the crude oil prices. Brown and Yücel (2008) argued that the relationship has complex short-term dynamics because of factors that affect market fundamentals such as extreme weather events, level of storage or disruption of production, but is quite stable in the long run.[33] Their empirical work calls for a continuum of market links as a result of more complex market forces. Empirical studies have examined this issue by testing for the presence of structural breaks and investigating a non-linear relationship between oil and natural gas prices. Ramberg and Parsons (2012) find evidence for structural breaks in 2006 and 2009 in the cointegrating relationship. Along this line, Brigida (2014) modeled structural breaks in the relative pricing relationships as switches between cointegrating regimes and finds that the decoupling was a temporary shift in regime. Using Student-t copulas to model the non-linear links between crude and natural gas prices, Grégoire et al. (2008) find evidence of extreme co-movement as well. Theoretical and empirical insights suggest a non-linear price transmission as most of the energy commodities exhibit non-linear behavior because of, among others, recessions, unforeseen extreme events, transaction costs, market power, geopolitical tensions, asymmetric information or stickiness in prices. The difference of the market structure also matters: as the oil market is global and responds more quickly to global factors whereas natural gas prices respond more to the regional dynamics of the markets.

Secondly, over a medium-term horizon, LNG markets will still experience a transition period during which oil-indexation, especially for the major importer (Japan), will still underpin contracts with limited reliance on spot trade.[34] The long road towards a liquid trading hub in Asia (requiring 5 to 10 years) and the enigmatic role of portfolio players who buy gas-indexed volumes and resell with oil-indexed formulas (IEA/OECD, 2016) will substantially anchor the oil price dynamics to that of the natural gas in the near future.

[32] Measured as the sample standard deviation of adjusted log price changes by using WTI spot prices.

[33] Erdős (2012) finds that oil and gas prices are close substitutes and should form a long-run equilibrium level close to the thermal parity around which they switch in the short run.

[34] Oil indexation in Asia is expected to slightly decrease, moving from 78% in 2016 to 69% in 2022 (Rogers, 2017).

The implications of the above findings are twofold. First, there is a strong correlation between oil and gas prices, and this relationship has to be modeled as non-linear.

Last but not least, oil price uncertainty has direct effects on global economic activity. This question has been studied by a huge strand of the economics literature pointing out different transmission channels. For instance, Elder and Serletis (2010) find that uncertainty overthe price of oil had a negative and significant effect on real gross domestic products (GDP), durables consumption, several components of fixed investment and industrial production. In the same vein, theories of investment under uncertainty and real options suggest that an asymmetric relationship between uncertainty and economic activity tends to postpone firm's decision-making when committing irreversible investments by creating an « option value to wait and see ». Such micro decisions are likely to affect the macro-level dynamics by creating cyclical fluctuations: as explained by Bernanke (1983), this could be the result of an economic system that is not sufficiently diversified or a misperception about the duration of the shock by agents under imperfect information who tend to extend in time the effects of a temporary shock.[35]

4.3.2. Oil price volatility

Oil price volatility, found to be a significant predictor of natural gas returns (Pindyck, 2004), is measured as the sample standard deviations of adjusted log price changes by using weekly WTI spot prices. Following Chen and Hsu (2012), the monthly volatility of WTI spot prices is considered:

$$wtivol_t = \sqrt{\left(\frac{1}{N-1}\right)\sum_{t=1}^{N}(r_t - \frac{1}{N}\sum_{t=1}^{N} r_t)^2} \tag{6}$$

$$r_t = log(wti_t^w) - log(wti_{t-1}^w) \tag{7}$$

with r_t the weekly oil price returns and N the number of trading weeks during the t month. Several reasons explain this choice: First, as highlighted by Pindyck (2004), spot prices represent the best single statistic for market conditions when considering their capacity to reflect the volatility of current and future values of production, consumption and inventory demand. Secondly, by using a standard deviation as a measure, we attribute the same weight to the observations used in the estimation. Campbell et al. (2001) emphasize the benefit of such an approach that does not require any parametric model to describe the evolution of volatility over time. It also provides unbiased estimators of the underlying latent volatility (see Fleming et al. (2001) and Radchenko (2005)).

Lastly, an interesting result from Ewing et al. (2002) consolidates our choice. By empirically modeling time-varying conditional variances of returns calculated from natural gas and oil indexes in a multivariate GARCH frame, they find that volatility persistence is less important in the oil market than in the gas market meaning that the return of volatility to its long-run level is faster in the case of oil returns. This result suggests that the unconditional variance of the series would yield a good forecast of the future volatility.

Hence, the approach we have retained to deal with the latency nature of return volatility enable us to imbed the oil price volatility in the VAR system as a function of its lagged value and

[35] The uncertainty over the future path of oil has also been found to be a decreasing factor of international trade flows (Chen and Hsu, 2012).

values of the natural gas prices returns in US, Japanese and European markets and will act as a non-linear propagator of shocks in those markets.

4.4. *Non-linear impulse responses*

In the class of non-linear models, some properties of linear models no longer hold namely the impulse responses can no longer be directly derived from the estimated coefficients, the responses are no longer symmetrical in terms of sign and size to structural shocks and, above all, impulse responses are no longer constant since the variance-covariance matrix of the residuals depends on the considered regime.[36] The non-linear impulse response function (NIRF) is the change in the conditional expectation of Y_{t+k} as a result of knowing the value of an exogenous shock:

$$E[Y_{t+k}|\Omega_{t-1}, u_t] - E[Y_{t+k}|\Omega_{t-1}] \tag{8}$$

where Y_{t+k} is a vector of variables at horizon k, Ω_{t-1} is the information set available at time t-1 and u_t is a particular realization of exogenous shocks. Besides, the calculation of the impulse response functions for the non-linear model requires a specification of the size and sign of shocks and the initial condition. We proceed by simulating the model conditional on an initial condition Ω_{t-1} and a given realization of u_t.[37]

4.5. *Simulation-Based Forecasting*

As the multivariate forecast errors are asymptotically normally distributed with covariance matrix, the forecasts of Y_{t+h} are simulated by generating multivariate normal random variables with mean zero and covariance matrix from the residuals of the estimated TVAR. More specifically, we generate Multivariate Monte-Carlo Simulations to get the future LNG prices paths for each regime of volatility as the TVAR model is linear within each regime and the subsequent shipping decisions to obtain the distribution of values for the diversion option. This choice is empirically supported by the results of the Andersen-Darling normality test applied to the TVAR model residuals distribution in each regime.

5. Regime-dependent volatility transmission

5.1. *Tests for TVAR and estimation of the threshold value*

Table 4 presents results of the test of a linear VAR model against the alternative threshold effect. To test the null hypothesis of linearity (1 regime) against the alternative of nonlinearity (with 2 or 3 regimes), we relied on a multivariate extension of the linearity test of Hansen (1999) and Lo and Zivot (2001). The LR test statistic is calculated in the following way:

$$LR_{01} = T(ln(det(\hat{\Sigma}_0) - ln(det(\hat{\Sigma}_1)) \tag{9}$$

with $\hat{\Sigma}_0$ the estimated covariance matrix of the model under the null hypothesis of linearity and $\hat{\Sigma}_1$ the estimated covariance matrix under the alternative hypothesis of a threshold specification. The p-values are calculated by simulation. [38] Three tests are computed. The both two (panel A and B

[36] See Gallant et al. (1993) and Koop et al. (1996).

[37] The employed algorithm for GIRFs computation is described in Appendix B.

[38] Based on 500 replications, the bootstrap distribution is obtained by resampling the residuals from the null hypothesis model, estimating the threshold parameter and then computing the test.

LR test results	
Panel A: LR test for linearity against 2 regimes	
LR statistic	154.774
p-value	[0.008*]
Estimated threshold	0.0386
Panel B: LR test for linearity against 3 regimes	
LR statistic	276.6101
p-value	[0.0300**]
Estimated thresholds	0.0386 0.0502
Panel C: LR test for 2 regimes against 3 regimes	
LR statistic	121.836
p-value	[0.404]
Estimated threshold	0.0386 0.0502

Note: The response of LNG prices to changes in volatility context is supposed to occur with a delay d of 2 months. P-values based on Hansen's (1996) procedure method of inference with 500 replications are between brackets. *, ** denote the rejection of the null hypothesis at 1% and 5% respectively.

Table 2: LR test results for a VAR(3)

in Table 4) can be considered as linearity tests whereas the third (Panel C in Table 4) can be seen as a specification test to check whether one or two thresholds are preferable. Results consolidate the choice of a threshold specification with two regimes of volatility that have one threshold. A better overview of this threshold effect is depicted in Figure 1A in Appendix A which represents the evolution of the uncertainty measure and the threshold estimated value above which the market toggles to the highest regime. It shows that oil prices react to major exceptional events: such as the 1997 Asian financial crisis, 2005 Hurricane Katrina, Global financial crisis of 2007-2008, the Fukushima disaster in 2011, and oil price slump in 2014. The uncertainty generated by these episodes of high volatility represents nearly 35% of the observations. The remainder is attributed to relatively low volatility regimes.

5.2. Non-linear impulse response functions

Figures 1B to 3B in Appendix B illustrate the estimated impulse response of liquefied natural gas returns to positive and negative shocks from oil price volatility in high regime (HR) and low regime (LR) configuration.[39] Overall, the non-linear impulse responses suggest that oil price volatility has a negative effect on natural gas returns in the three regions regardless of the regime. As discussed before, this result is with respect to the increased uncertainty of current and future oil price trajectories, consumption and inventory demand that will give credence to the « option value to wait » of investments, thereby delaying the consumption. More importantly, for all the regional price returns, the impact of oil price volatility shocks exhibits an asymmetrical phenomenon as it is more significant in the high case scenario: a result that consolidates the choice of the threshold specification with the oil price volatility as a non-linear propagator of shocks.

[39]Four lines are displayed, corresponding to positive and negative nonlinear impulse response functions (IRFs) under high and low volatility states following a two-standard-deviation oil price volatility shock.

As one could expect, disparate impacts are wielded by oil price volatility shocks in the three regional markets. This result could mainly be explained by the differences in the oil dependence scheme and the natural gas market structures. Asian gas returns are the most responsive (in period 1) to a positive oil price volatility shock regardless of the considered regime. This result directly echoes the oil dependence of the country and the huge recourse to the oil-indexation in the LNG contracting structure.

Concerning the European market, there are some lag effects (period 3) in the gas returns response to a positive shock from oil price volatility when the market is already in a high regime of volatility. This lag effect might be explained by the relatively large share of domestic gas production and pipeline import, the hybrid system of price formation and the competition with other energy sources that tend to postpone the effect of oil price volatility. Whatever the sign and the considered regime, there is a hysteresis effect in the European response to shock from oil price volatility with a slow return to the pre-shock values.

In the highest regime, North American gas returns have experienced a quick redirection toward their pre-shock values: the transitory nature of this response is indicative of the partial influence of oil prices dynamics in the US gas market, as the latter widely responds to its own supply and demand issues, storage level considerations, etc. This result is supported by the slightest difference between the response of gas returns in the high and low regime of volatility which is indicative of the reliance on the derivatives products to manage their risks.

5.3. Robustness checks

Overall, our results are found to be robust to different specifications of the threshold VAR model and the variables. More specifically, our conclusions are robust to variations in the number of lags in the TVAR system, to different delays d of the transition variable, and different orders of the moving average process.[40] Moreover, results are also robust to a threshold variable measured by using daily WTI spot prices to calculate the sample standard deviations of adjusted log price changes.[41] Finally, we have considered an other proxy of uncertainty to test the robustness of the model to another transition variable. Following Bloom (2009), we retained the Chicago Board of Exchange VXO stock market volatility measure constructed using the implied volatilities on S&P 500 index options.[42] The latter is reputed to provide a measure of financial market uncertainty and shows the market's expectations of 30-day volatility and is hence primarily forward-looking. As it turns out, this alternative threshold variable makes little difference in terms of our testing of a threshold specification and also in terms of conclusions of the impulse response functions.[43]

6. Destination flexibility option

6.1. Regime-dependent LNG prices paths

We will associate the high scenario to an increased uncertainty about the use of oil-indexation in long-term LNG contracts. An increasing oil price volatility could affect their duration and give

[40] Tables 1F, 2F and 3F in Appendix F present tests of a linear VAR against a threshold alternative. Three tests are computed: sup-Wald, avg-Wald and exp-Wald, which respectively represent the maximum, average and function of the sum of exponential Wald statistics over all possible threshold values (See Hansen (1996) for the simulation method used here to conduct inference).

[41] See Table 1E and Figures 1E to 3E in Appendix E.

[42] The number of lags in the VAR was set to three.

[43] See Table 2E and Figures 4E to 6E in Appendix E.

a significant impetus to the willingness of Asian markets to push forward gas-to-gas competition. This could lead to a situation where buyers would tend to not renew their expiring contracts and would choose to enter into shorter spot indexed contracts. We will associate the low scenario with a persisting high reliance on oil-indexation and a relatively slow beginning of large US LNG volumes being exported to the global gas market.

6.2. Free destination option

To capture the dynamics of future flows by 2020 and determine the adapted shipping decisions, we have chosen to calculate the value of the free destination option for producers located in the US, Australia, Africa, and Middle East. Table 3 gathers the result for all tested configurations. Figures 1D to 6D in Appendix D depicts the cumulative frequency distribution throughout the 10,000 Monte Carlo simulations of monthly unit value of the free destination option in low and high regime of volatility for producers involved in transatlantic arbitrages with a map in Figure 2.

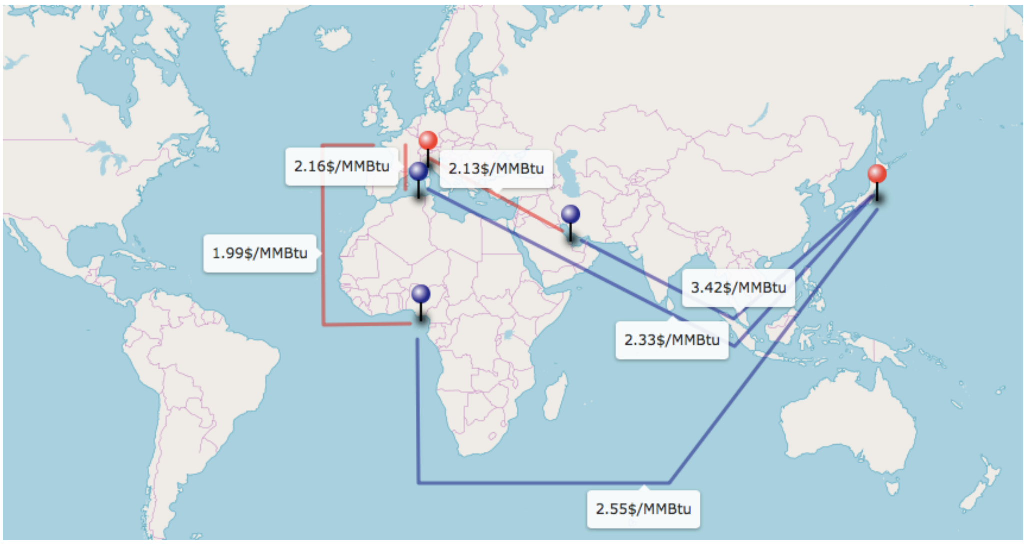

Figure 2: Expected value of free destination option when suppliers are initially commited to serve US in the high regime

Note: Blue spots represent the suppliers locations, Red spots are the European and Japanese alternative markets, Red (Blue) lines represent the derouting of LNG toward the European (Japanese) market and the associated value of the free destination option.

Australia. As the looming prospect of large new LNG supplies by 2020 is partly coming from Australia, analyzing the spread-responsive LNG cargo movements from this region should be instructive. We consider four case scenarios and each one is related to the above described high and low regimes of volatility. In the first one, we compare a base case in which an Australian supplier could flow LNG only to Japan (the most reasonable destination in terms of shipping costs) [44] and a free destination case that allows for diverting LNG cargoes toward the European

[44] See tables 1C and 2C in Appendix C.

Supplier	Initial	Alternative	Volatility Regime	Flexibility option	Gain
Most profitable studied cases					
Qatar	US	Japan	High Regime	3.42$/MMBtu	172%
			Low Regime	1.55$/MMBtu	156%
Algeria	US	Japan	High Regime	2.33$/MMBtu	70%
			Low Regime	0.94$/MMBtu	62%
Nigeria	US	Japan	High Regime	2.55$/MMBtu	103%
			Low Regime	1.06$/MMBtu	85%
Transatlantic arbitrages					
Qatar	US	Europe	High Regime	2.13$/MMBtu	109%
			Low Regime	0.90$/MMBtu	90%
Algeria	US	Europe	High Regime	2.16$/MMBtu	82%
			Low Regime	0.93$/MMBtu	70%
Nigeria	US	Europe	High Regime	1.99$/MMBtu	81%
			Low Regime	0.84$/MMBtu	67%
Japan / Europe arbitrages					
Australia	Japan	Europe	High Regime	0.02$/MMBtu	1%
			Low Regime	0.00$/MMBtu	0%
US	Europe	Japan	High Regime	1.07$/MMBtu	25%
			Low Regime	0.41$/MMBtu	20%
Qatar	Japan	Europe	High Regime	0.32$/MMBtu	6%
			Low Regime	0.06$/MMBtu	2%
Algeria	Europe	Japan	High Regime	0.84$/MMBtu	18%
			Low Regime	0.27$/MMBtu	12%
Nigeria	Europe	Japan	High Regime	1.06$/MMBtu	24%
			Low Regime	0.38$/MMBtu	18%

Note: "Initial" refers to the agreed destination in the long-term LNG contract, "Alternative" is the diverting option and the "Gain" column features the flexibility option/inflexible project value ratio.

Table 3: Expected values of the free destination option in a high and low regime of volatility

markets. Following the methodology described above, the monthly average unit value of destination flexibility in this case is found to be equal to \$0.02 per MMBtu in the highest regime and \$0.00 per MMBtu in the low case scenario. Here, the flexibility to respond to market price signals does not improve the expected value of an LNG project compared to an inflexible project as there is little chance to see a supplier from Australia engage in this physical arbitrage when transportation costs differentials are threefold. The optimization of LNG flows saliently explains this interpretation as the low oil and gas price environment has prominently tightened margins, not counting the additional costs incurred when the diversion option is exercised. Altogether, whatever the level of uncertainty that weighs on Japanese and European demand and the pace at which the transition toward a more flexible LNG market will move away from oil indexation, the looming new LNG supply from Australia would remain in the region when original contracts plan to send LNG to Japan. As the portfolio of Australian LNG supply could be diversified, we have also studied three other cases by comparing a base case in which an Australian LNG supplier is initially committed to the US market and a free destination case where LNG is able to be diverted either to Europe or Japan or both. The contingency of these situations has to be considered as a way to widen the sphere of possibilities in terms of shipping decisions in a portfolio perspective rather than an exclusive optimization of shipping distances. It appears that the price spread stimuli between the markets in the US and Europe/Japan leads to the optionof destination flexibility to be exercised regardless of sizeable extra maritime costs. For instance, the ability to respond to European market price signals allows for an 89% improvement in a high case scenario and for a 74% improvement in the lowest regime.

US. Arbitrage decisions underpinned by the new wave of US LNG are equally of paramount importance.[45] Two cases are analyzed here: the first one embodies an American supplier which is committed to flowing LNG to Europe and evaluates the possibility to redirect its cargoes to Japan as an alternative destination. To give more support to the latter shipping decision, a second case exemplifies an American supplier which is initially involved in a long-term contract with Japan and sees in the European market a way to benefit from arbitrage opportunities. In terms of extra maritime costs, it is about twice as expensive for an American supplier to ship an LNG cargo to Japan as it is to Europe: this feature does not undermine the diversion decision of LNG cargoes in the first case. In this present instance, a \$1.07 per MMBtu is expected for the flexibility option in the high regime and \$0.41 per MMBtu in the low regime. In the adverse case, the value of free destination for a unit production capacity is expected to represent on average of \$0.16 per MMBtu in the low scenario case and \$0.56 per MMBtu in the high scenario case. More precisely, the distribution of the value of destination flexibility varies from zero to \$2.24 per MMBtu with a standard deviation of \$0.80 per MMBtu in the high case scenario and oscillates from zero to \$0.71 per MMBtu with a standard deviation of \$0.25 per MMBtu in the low case scenario. Hence, the Atlantic Basin is well positioned to take a turning point and become an important LNG arbitrage market by horizon of 2020 especially in a context of an increased uncertainties about the future path of LNG demand in Europe and Japan.

Middle-East. The Middle East counts major players in the LNG industry. Even though some producers will see their export-oriented LNG production drop as Abu Dhabi or Oman, the stability of a key player such as Qatar will keep ensuring LNG flows from this region. The increase

[45] The associated probability distributions of the free destination option are available upon request.

in capacity was phenomenal between 2009 and 2011 in Qatar, which resulted in large spare capacity that was able to significantly affect the dynamics of future LNG flows.[46] In a context of a producer initially engaged in the medium term on a contract with the United States,[47] the potential benefits of diverting LNG cargoes to Europe and Japan are both analyzed.

When the latter has to arbitrate between the US and Europe, it appears that the monthly average unit value of destination flexibility is calculated at \$2.13 per MMBtu in the high case scenario and \$0.90 per MMBtu in the low case scenario (see figures 1D and 2D in Appendix D). This is a significant value when reconsidering the relatively bleak outlook of LNG prices on the medium-term horizon. This decision turns out to be rational enough to be concretized as there is no huge extra-maritime cost (\$0.02 per MMBtu). Moreover, the decision to divert its LNG cargoes to the Japanese market is equally feasible: the monthly unit value of destination flexibility in this case totals \$1.55 per MMBtu in the low case scenario and \$3.42 per MMBtu in the high scenario case , the monthly average unit value of the destination flexibility option is about \$2.13 per MMBtu in the high case scenario and \$1.68 per MMBtu in the low case scenario.[48] The improvement provided by the flexibility option here is 1.72 times higher in a high scenario case and 1.56 higher in low scenario case compared with the case where the only destination alternative was the US.

Africa. Finally, we have chosen to calculate the value of the destination flexibility option for a country in North Africa (Algeria) and in West Africa (Nigeria) whose production forecasts for 2020 are substantial (IGU, 2017). These countries have also shown by past diversions of LNG cargoes that they are very inclined to this type of practice. These two countries share in common their close link to the European market that receives LNG from these countries on a regular basis and have fairly comparable transportation cost differentials in that the Japanese market is far more laborious to reach than the European or US market.[49] As a first case, we then calculated the medium-term gains associated with a possible diversion of LNG cargoes initially committed to Europe to the Japanese market. Whether from Algeria or Nigeria, the conclusions are unanimous: the free destination option has more chance of being exercised in the high regime. Nonetheless, whatever the considered volatility regime, the expected value of the option is found to be less profitable comparing to the transatlantic options (see Table 3). The end of the "boundless" Asian premium following the Fukushima disaster should give less rationality to this decision.

Two other cases are focused on Nigerian and Algerian suppliers who are initially committed to serve the US markets and study the possibility of diverting these cargoes to Europe or Japan (See Figures 3D to 6D in Appendix D). When Europe takes the role of alternative market , the monthly average unit value of destination flexibility is found to be equal to \$1.99 per MMBtu in the high case scenario and \$1.12 per MMBtu in the low case scenario for a Nigerian supplier and reaches \$2.16 per MMBtu in the high case scenario and \$0.93per MMBtu in the low case scenario from an Algerian supplier point of view. These results reflect a high probability of exercising the option in the medium-term horizon as with 90% certainty, the value of the free destination option is about to vary from \$1.12 per MMBtu to \$3.02 per MMBtu in the high case

[46] This production is mainly due to low production costs which explains the resilience of the latter to a low oil price environment.

[47] A case that echoes the large production capacity that was intended to this market before the American shale gas revolution.

[48] And with 90% probability, this value ranges from \$1.24 per MMBtu to \$1.64per MMBtu in the low case scenario and from \$1.77per MMBtu to \$7.38 per MMBtu in the low case scenario

[49] See Table 11.

scenario and from \$0.69 per MMBtu to \$0.99 per MMBtu in the low scenario case when a Nigerian supplier is free to divert its cargoes to Europe. The same improvement is expected on the Algerian side as the free destination option has the potential to bring an added value of around 82% in a high scenario case and 70% in a low scenario case compared to a geographically constrained project. In the same vein, when Japan is considered as the market destination of diverted LNG cargoes, the option of free destination is slightly less significant than in the European case for Algerian suppliers but increases from a Nigerian supplier point of view.

As part of our modeling, by increasing extra transportation costs to alternative markets from 10% to 50%, we find that for all suppliers involved in US-Japan and US-Europe arbitrages, the value of the free destination option turns out to be slightly more sensitive to extra-transportation costs when the market is under high volatility. By contrast, when the arbitrage decision hinges on the dynamics of the Japanese and European markets, it's not only the value of the option that is necessarily higher in the more volatile regime but also the sensitivity to the additional maritime costs.[50] In all cases, given the weak oil and gas environment, particular attention will be paid to transportation costs which, combined with future price trajectories, will prominently drive diversion decisions.

7. Discussion

In comparison with the results obtained in the Yepes Rodríguez (2008) study, the value of the flexibility option remains a very important part of the value of LNG, and even more so on a monthly basis. Taking into account the volatility of oil prices, which is supposed to capture the pressure on the practice of oil indexation and partly the uncertainties related to global activity, three important points are to be emphazised.

First, the results described above show that the price differentials between the US and Europe/Asia will still be very significant in the coming years, creating considerable arbitrage opportunities. Indeed, our model has shown that for a producer located in Nigeria, Algeria or Qatar that must initially deliver the US market, it will always be profitable to exercice their right to diverge to Europe or Japan (see figure 2).

Secondly, arbitrage opportunities are found to be more profitable in the highest regime of oil price volatility. Associated to an increased uncertainty about the practice of oil-indexation in long-term LNG contracts, this result echoes the study of Zhang et al. (2018) that sought to understand whether higher prices in Asia are due to pricing discrimination or simply reflect differences in the market fundamentals. From this point of view, our results suggests that oil indexation has probably had a significant impact on the Asian premium as the pressure on oil stability and thus the indexation process pushes Japanese prices to be more sensitive to uncertainties in fundamentals. This also means that the more the market swiftly repositions to a more flexible reconfiguration, ultimately involving the dissolution of destination clauses and the use of a hub-pricing in all contractual terms, the more the players of this industry will be inclined to commit and take advantage of arbitrage opportunities. Focusing on destination flexibility will thus be an effective way of giving some momentum to a quasi-inescapable transition period for

[50] In a more relevant and exhaustive way, shipping market has to be considered here as a market itself. The latter is significantly affected by the economic business cycle, the ordering of new vessels and the subsequent balance of tanker supply and demand, on market expectations or on the lag between the start of liquefaction and the delivery of dedicated vessels.

the Asian markets. In this respect, our results are in perfect agreement with those of Shi and Variam (2016) who advocate a prioritization of the destination issue in the contractual terms of LNG sales.[51]

Thirdly, our results suggest the end of the Asian premium with a tightening of price differentials between Europe and Asia, whatever the volatility regime considered (see Table 3). Indeed, in both high and low regime, producers from US, Algeria or Nigeria will probably not systematically exercise a diversion right to divert a shipment originally scheduled for Europe to Asia.

Finally, the low price environment for oil and gas industry and the subsequent tight margins are prominently calling for an optimization of LNG flows in the medium-term horizon. The greater the transport distances are, the greater the uncertainty that weighs on the days of travel, fuel costs and labor costs. From this point of view, the exercise of the valued options might give an indication of the direction of future LNG flows by 2020 that will depend on the two possible scenarios: a high case scenario under which the above described uncertainties about future LNG demand in Europe and Japan are exacerbated and where the transition to a more flexible LNG market away from oil indexation is occurring at a sustained pace and a low case scenario that does not really deviate from the current market configuration with a time-consuming transition. Thereby, one might expect that: US LNG would prominently go to Europe in both scenarios but is more likely to end up in Europe in a low case scenario; Australian and Middle Eastern LNG are expected to be moved toward the Japanese market and the European alternative would be profitable only when a producer in one of the two regions is initially committed to serving the US for both scenarios; and an African LNG will be found mainly in Europe with a higher probability of diverting an Algerian LNG to Japan than a Nigerian LNG given its lower sensitivity to extra maritime costs. As highlighted by Corbeau and Ledesma (2016), the high transaction cost LNG market is obviously not at a stage where LNG flows can be perfectly optimized. Logistical, operational and contractual bottlenecks are actually putting off the prime essence of the LNG industry: that of being a cargo business. For instance, the need for the compatibility of the offloading and the receiving infrastructure, the possible limited berth availability at terminals or the size restriction in accordance to the receiving liquefaction terminal show how the lack of standardization from an infrastructure point of view can pose significant barriers to LNG trade. And when considering the diversion decision, the additional costs can seriously deter the exercise of the option as it might imply that the supplier fulfills its commitments to the initial buyer by supporting all additional costs of the replaced LNG in addition to the question of rent-sharing which is also a government issue, bunker fuel costs, boil-off gas equivalent fees, charter costs, regas fees and costs to access to regasification terminals in the alternative market. All the complexity of these decisions is based on the fact that evolving physical, cost, and pricing aspects must be considered in tandem.

8. Conclusion

In fine, what could be learned from the destination flexibility option in the LNG markets? As mentioned above, LNG is a cargo business that makes the ability to move gas by sea over long

[51] For two main reasons: the first being that a removal of destination clauses does not suggest the liberalization of the domestic market and would therefore be much easier to implement compared to a change of indexation; secondly, importing governments should have the sovereignty to prohibit firms under its competence to sign contracts with destination clauses, such as in the case of European Union.

distances the cornerstone for splitting natural gas markets from their regional dynamics. A speculation on the possibility of converging regional LNG prices requires a cautious interpretation of the valued destination flexibility option. Expecting an integration of natural gas markets by the only effect of appropriation of best netbacks when suppliers can choose their ultimate market destination could be misleading. Here, the shortfall of geographically constrained producers rather highlights the benefits of greater future market spotification as even partners engaged in long-term contracts could profit from a participation in the spot market, thus increasing the liquidity of the latter. If it goes in tandem with a lower indexation of oil prices and market forces driving prices and movements of vessels, then in this precise case, one would expect a possible "convergence". The transition to this state suggests looking closely at the process of liberalization of national gas markets, the pricing terms in forthcoming long-term contracts and the expansion of spot trade and its legitimacy in establishing itself as a reference for long-term LNG contracts. The question of the impact of destination flexibility would therefore have to do with the time horizon considered. In the medium-term, it would be misleading to combine greater destination flexibility with a systematic price convergence mechanism as regional price formations remain intrinsically too divergent by responding to fundamentally different dynamics. At the limit, one could expect a convergence of regional prices. In the long run, if long-term contracts are able to completely get rid of oil indexation with an increased spot trade, these conditions would make flexibility destination a serious barrier in less to global LNG trade. Destination flexibility is one piece of the puzzle as global LNG trade is prone to remain strongly constrained by costly infrastructure challenges and logistical barriers. Nonetheless, the strong willingness for increased flexibility in the LNG market could bring new liquefaction technologies that will change the way to address the issue of flexibility in the destination, as evidenced by the Coral FLNG project in Mozambique.

Notwithstanding the value of our findings, our analysis can be extended in several directions. First of all, one could ambition to extend the analysis to incorporate the dynamics of the shipping market (i.e., the price formation and the volatility of the freight rates used for LNG tankers instead of the simple point estimates used in the present work). Indeed, the LNG market, historically stable, has been recently experiencing substantial changes over the last decade as the share of vertically integrated LNG trading companies owning tankers has declined whereas short-term chartering practices based on spot market rates are more and more frequent. However, to the best of our knowledge, this kind of investigation can hardly be conducted at present because of a lack of publicly available data. Should that limitation be slackened, an analysis incorporating that shipping dimension could offer an interesting avenue for future research. Another strand of research could also extend the geographical scope of our analysis by incorporating other LNG importing markets, such as the emerging ones in Latin America and Asia (e.g., China, India) where demand is expected to noticeably increase in the coming years.

9. Acknowledgements

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10. References

References

Balke, N.S., 2000. Credit and economic activity: credit regimes and nonlinear propagation of shocks. Review of Economics and Statistics 82, 344–349.

Barnes, R., Bosworth, R., 2015. LNG is linking regional natural gas markets: Evidence from the gravity model. Energy Economics 47, 11–17.

Bernanke, B.S., 1983. Irreversibility, uncertainty, and cyclical investment. The Quarterly Journal of Economics 98, 85–106.

Bloom, N., 2009. The impact of uncertainty shocks. E conometrica 77, 623–685.

Brigida, M., 2014. The switching relationship between natural gas and crude oil prices. Energy Economics 43, 48–55.

Brown, S.P., Yücel, M.K., 2008. What drives natural gas prices? The Energy Journal , 45–60.

Campbell, J.Y., Lettau, M., Malkiel, B.G., Xu, Y., 2001. Have individual stocks become more volatile? an empirical exploration of idiosyncratic risk. The Journal of Finance 56, 1–43.

Chen, S.S., Hsu, K.W., 2012. Reverse globalization: Does high oil price volatility discourage international trade? Energy Economics 34, 1634–1643.

Cogan Jr, J.P., 2006. Contracting practices evolve for new global lng trade. Oil, Gas & Energy Law Journal (OGEL) 4.

Corbeau, A.S., Ledesma, D., 2016. LNG markets in transition: the great reconfiguration. Oxford University Press for the Oxford Institute for Energy Studies and the King Abdullah Petroleum Studies and Research Center.

Creamer, G.G., Creamer, B., 2014. A non-linear dependence analysis of oil, coal and natural gas futures with brownian distance correlation, in: 2014 AAAI Fall Symposium Series.

Creti, A., Villeneuve, B., 2004. Longterm contracts and take-or-pay clauses in natural gas markets. Energy Studies Review 13.

Crocker, K.J., Masten, S.E., 1988. Mitigating contractual hazards: Unilateral options and contract length. The RAND journal of economics , 327–343.

Elder, J., Serletis, A., 2010. Oil price uncertainty. Journal of Money, Credit and Banking 42, 1137–1159.

Erdős, P., 2012. Have oil and gas prices got separated? Energy Policy 49, 707–718.

Ewing, B.T., Malik, F., Ozfidan, O., 2002. Volatility transmission in the oil and natural gas markets. Energy Economics 24, 525–538.

Fleming, J., Kirby, C., Ostdiek, B., 2001. The economic value of volatility timing. The Journal of Finance 56, 329–352.

Gallant, A.R., Rossi, P.E., Tauchen, G., 1993. Nonlinear dynamic structures. Econometrica: Journal of the Econometric Society , 871–907.

Glachant, J.M., Hallack, M., 2009. Take-or-pay contract robustness: A three step story told by the brazil–bolivia gas case? Energy Policy 37, 651–657.

Gray, J.A., 1978. On indexation and contract length. Journal of political Economy 86, 1–18.

Grégoire, V., Genest, C., Gendron, M., 2008. Using copulas to model price dependence in energy markets. Energy risk 5, 58–64.

Hansen, B., 1999. Testing for linearity. Journal of economic surveys 13, 551–576.

Hansen, B.E., 1996. Inference when a nuisance parameter is not identified under the null hypothesis. Econometrica: Journal of the econometric society , 413–430.

Hartley, P., Medlock III, K., Rosthal, J., 2007. An econometric evaluation of the demand for natural gas in the power generation and industrial sectors. James A Baker III Institute for Public Policy, working paper .

Hartley, P.R., 2015. The future of long-term lng contracts. The Energy Journal , 209–233.

Hubbard, R.G., Weiner, R.J., 1986. Regulation and long-term contracting in US natural gas markets. The Journal of Industrial Economics , 71–79.

IEA/OECD, 2016. Global gas security review, How flexible is the LNG market in practice?

IGU, 2016. World LNG report-2016.

IGU, 2017. World LNG report-2017.

Kao, C.W., Wan, J.Y., 2009. Information transmission and market interactions across the atlantic—an empirical study on the natural gas market. Energy Economics 31, 152–161.

Klein, B., Crawford, R.G., Alchian, A.A., 1978. Vertical integration, appropriable rents, and the competitive contracting process. The journal of Law and Economics 21, 297–326.

Klein, S., Frazier, G.L., Roth, V.J., 1990. A transaction cost analysis model of channel integration in international markets. Journal of Marketing research , 196–208.

Koop, G., Pesaran, M.H., Potter, S.M., 1996. Impulse response analysis in nonlinear multivariate models. Journal of econometrics 74, 119–147.

Lo, M.C., Zivot, E., 2001. Threshold cointegration and nonlinear adjustment to the law of one price. Macroeconomic Dynamics 5, 533–576.

Massol, O., Tchung-Ming, S., 2010. Cooperation among liquefied natural gas suppliers: Is rationalization the sole objective? Energy Economics 32, 933–947.

Masten, S.E., 1998. Contractual choice. University of Michigan Law School, Working Paper .

Matilla-García, M., et al., 2007. Nonlinear dynamics in energy futures. The Energy Journal 28, 7–30.

Neuhoff, K., von Hirschhausen, C., 2006. Long-term vs. Short-term Contracts; A European perspective on natural gas .

Neumann, A., 2009. Linking natural gas markets: is LNG doing its job? The Energy Journal , 187–199.

Neumann, A., Siliverstovs, B., Hirschhausen, C.v., 2006. Convergence of european Spot market prices for natural gas?A real-time analysis of market integration using the Kalman Filter. Applied Economics Letters 13, 727–732.

Pindyck, R.S., 2004. Volatility in natural gas and oil markets. The Journal of Energy and Development 30, 1–19.

Pirrong, S.C., 1993. Contracting practices in bulk shipping markets: a transactions cost explanation. The Journal of Law and Economics 36, 937–976.

Radchenko, S., 2005. Oil price volatility and the asymmetric response of gasoline prices to oil price increases and decreases. Energy economics 27, 708–730.

Ramberg, D.J., Parsons, J.E., 2012. The weak tie between natural gas and oil prices. The Energy Journal , 13–35.

Ritz, R.A., 2014. Price discrimination and limits to arbitrage: An analysis of global lng markets. Energy Economics 45, 324–332.

Rodríguez, R., 2008. Real option valuation of free destination in long-term liquefied natural gas supplies. Energy Economics 30, 1909–1932.

Rogers, H., 2017. Does the portfolio Business Model spell the end of long-term oil-indexed contracts?

Ruester, S., 2009. Changing contract structures in the international liquefied natural gas market: a first empirical analysis. Revue d'économie industrielle , 89–112.

Serletis, A., 1997. Is there an east-west split in north american natural gas markets? The Energy Journal , 47–62.

Serletis, A., Herbert, J., 1999. The message in north american energy prices. Energy Economics 21, 471–483.

Shi, X., Variam, H.M.P., 2016. Gas and *lng* trading hubs, hub indexation and destination flexibility in East Asia. Energy Policy 96, 587–596.

Siliverstovs, B., L'Hégaret, G., Neumann, A., Von Hirschhausen, C., 2005. International market integration for natural gas? a cointegration analysis of prices in europe, north america and japan. Energy Economics 27, 603–615.

Tong, H., 1990. Non-linear time series: a dynamical system approach. Oxford University Press.

Villar, J.A., Joutz, F.L., 2006. The relationship between crude oil and natural gas prices. Energy Information Administration, Office of Oil and Gas , 1–43.

Von Hirschhausen, C., Neumann, A., 2008. Long-term contracts and asset specificity revisited: An empirical analysis of producer–importer relations in the natural gas industry. Review of Industrial Organization 32, 131–143.

Walls, W.D., 1994. Price convergence across natural gas fields and city markets. The Energy Journal , 37–48.

Williamson, O.E., 1979. Transaction-cost economics: the governance of contractual relations. The journal of Law and Economics 22, 233–261.

Zhang, D., Shi, M., Shi, X., 2018. Oil indexation, market fundamentals, and natural gas prices: An investigation of the asian premium in natural gas trade. Energy Economics 69, 33–41.

11. Appendices

Appendix A: Evolution of the uncertainty measure and the estimated threshold value

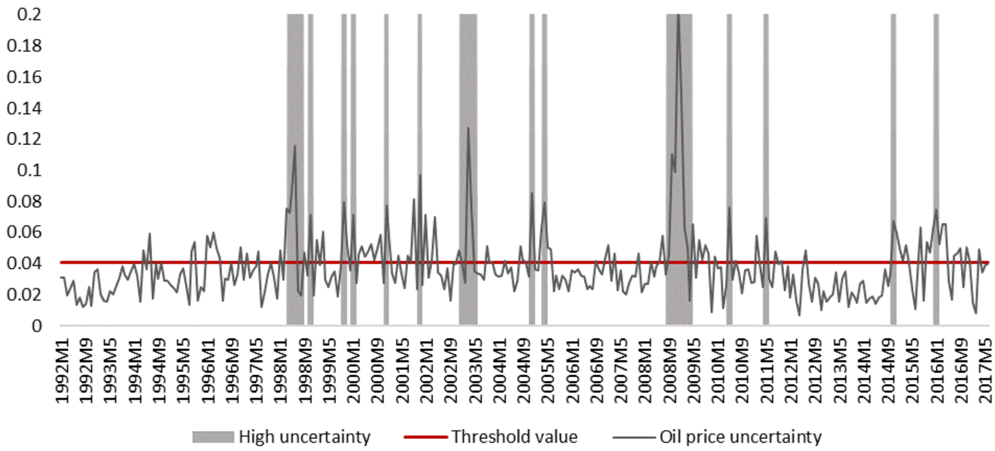

Figure 1A: MA(3) of Oil Price Volatility and estimated threshold

Appendix B: Algorithm for GIRFs computation and their representation

The method for computing generalised impulse response functions follows Balke (2000). The employed algorithm is the following:

1. Pick a history Ω^r_{t-1} of all the lagged endogenous variables of the model at a particular date.
2. Pick a sequence of shocks from the covariance matrix by bootstraping the estimated residuals of the TVAR model. The residuals are assumed to be jointly distributed.
3. Using this sequence of shocks, we produce forecasts conditional on initial conditions Ω^r_{t-1} by simulation.
4. We repeat step 3 by adding a new shock at time 0 equal to +/- 1 or 2 SD.
5. We repeat steps 2 to 4 are B times (B=500).
6. We repeat steps 1 to 5 R times and compute the average impulse response function as the average difference between the forecast from step 3 and 4.

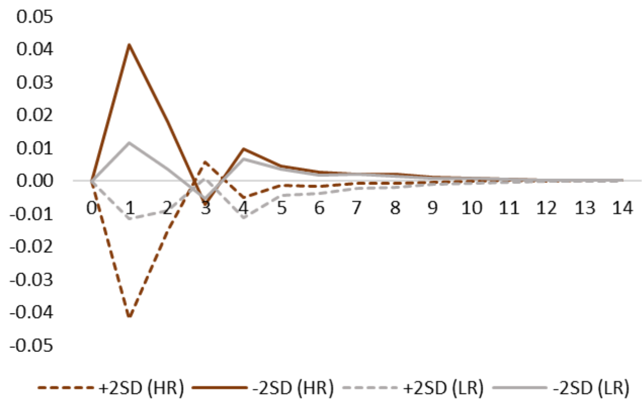

Figure 1B: JAP LNG response from oil price volatility* shocks of +/- 2 SD

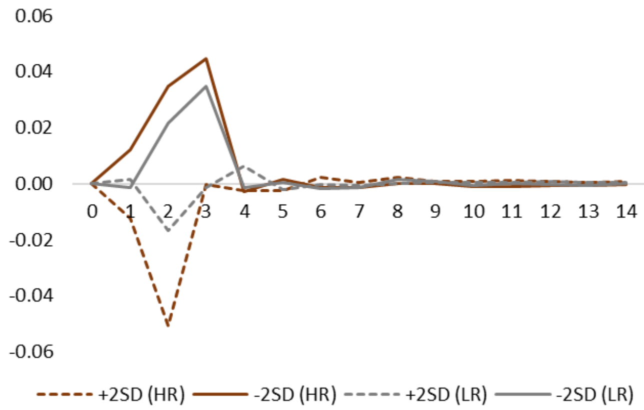

Figure 2B: US LNG response from oil price volatility shocks of +/- 2 SD

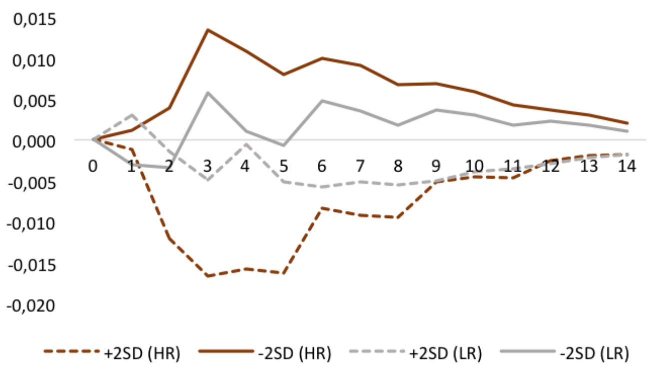

Figure 3B: EU LNG response from oil price volatility shocks of +/- 2 SD

Notes: The x-axis corresponds to the months.

*: Oil price volatility calculation is based on weekly oil price returns.

Appendix C: Shipping considerations

	Japan	South West Europe	North East US
Middle East	0.62	0.74	0.92
Australia	0.35	1.04	0.9
Nigeria	1.07	0.37	0.3
Algeria	1.23	0.08	0.19
US Gulf Coast	1.13	0.47	-

Source: Platts LNG Daily, 2016. Volume 13/ Issue 223.

Table 1C: Freight route costs ($ /MMBtu)

	Japan	South West Europe	North East US
Middle East	15	13*	22
Australia	8	21*	29
Nigeria	26	9	13
Algeria	24*	1	9
US Gulf Coast	2	12	-

Source: Platts LNG Daily, 2016. Volume 13/ Issue 223.

Table 2C: Shipping days

Appendix D: Cumulative probability distributions for 10.000 Monte-Carlo simulations with a 90% certainty level ($ /MMbtu)

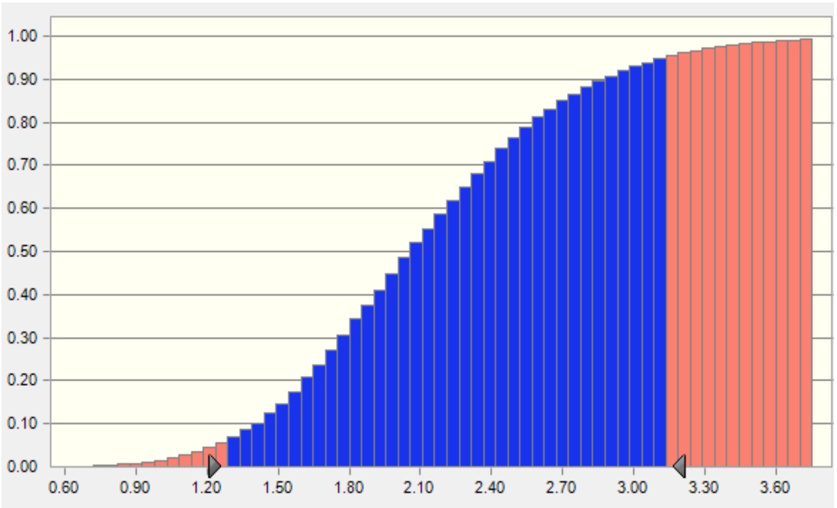

Figure 1D: Value of flexibility - High Regime - QATAR

Expected value = 2.13$ /MMBtu.
Lower limit value (10%) = 1.26$ /MMBtu.
Upper limit value (90%) = 3.15$ /MMBtu.

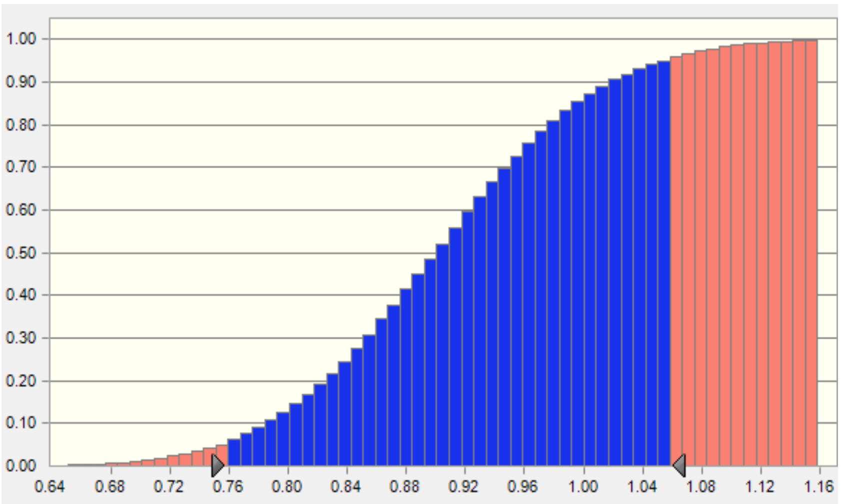

Figure 2D: Value of flexibility - Low Regime - QATAR

Expected value = 0.90$ /MMBtu.
Lower limit value (10%) = 0.76$ /MMBtu.
Upper limit value (90%) = 1.06$ /MMBtu.

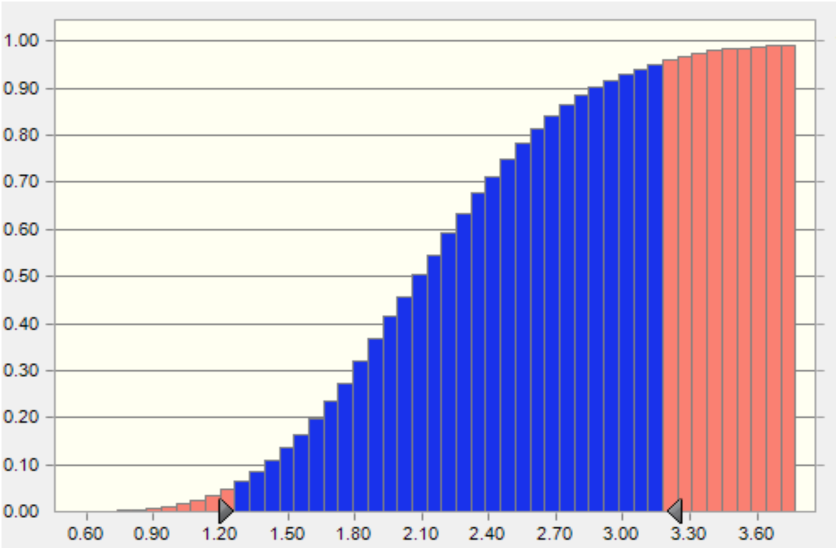

Figure 3D: Value of flexibility - High Regime - ALGERIA

Expected value = 2.16$ /MMBtu.
Lower limit value (10%) = 1.27$ /MMBtu.
Upper limit value (90%) = 3.18$ /MMBtu.

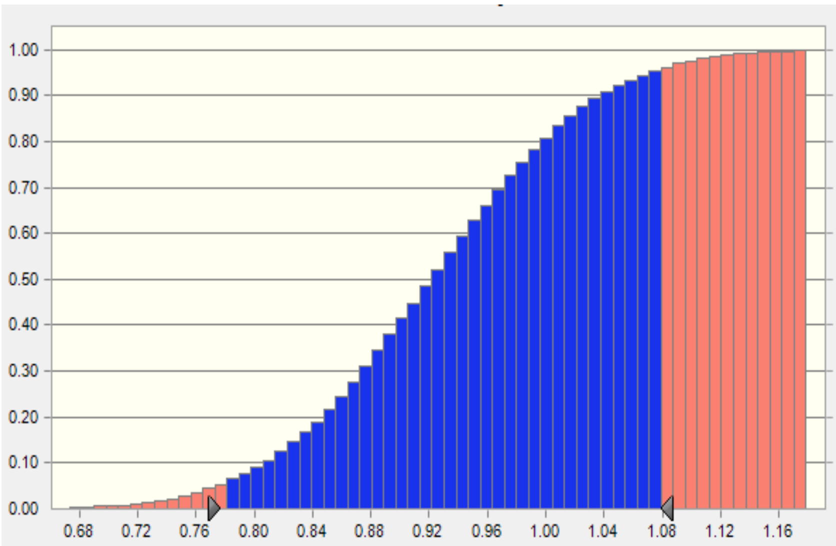

Figure 4D: Value of flexibility - Low Regime - ALGERIA

Expected value = 0.93$ /MMBtu.
Lower limit value (10%) = 0.78$ /MMBtu.
Upper limit value (90%) = 1.08$ /MMBtu.

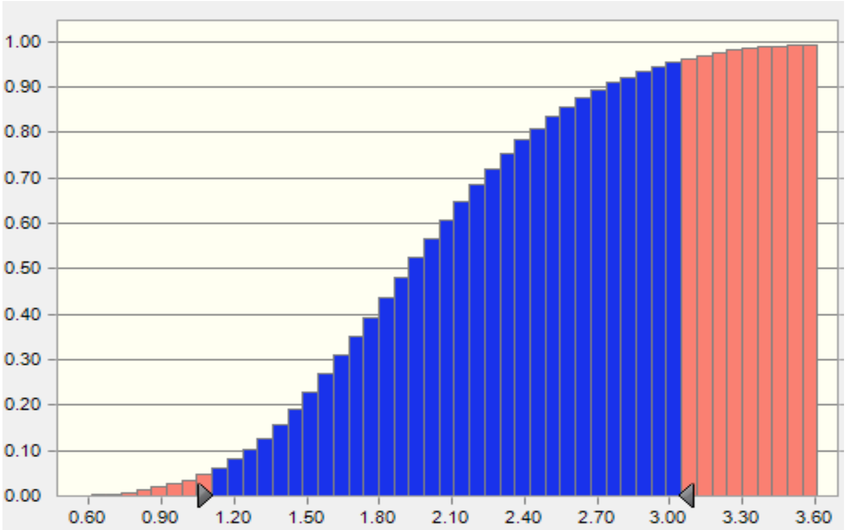

Figure 5D: Value of flexibility - High Regime - NIGERIA

. Expected value = 1.99$ /MMBtu.
Lower limit value (10%) = 1.12$ /MMBtu.
Upper limit value (90%) = 3.02$ /MMBtu.

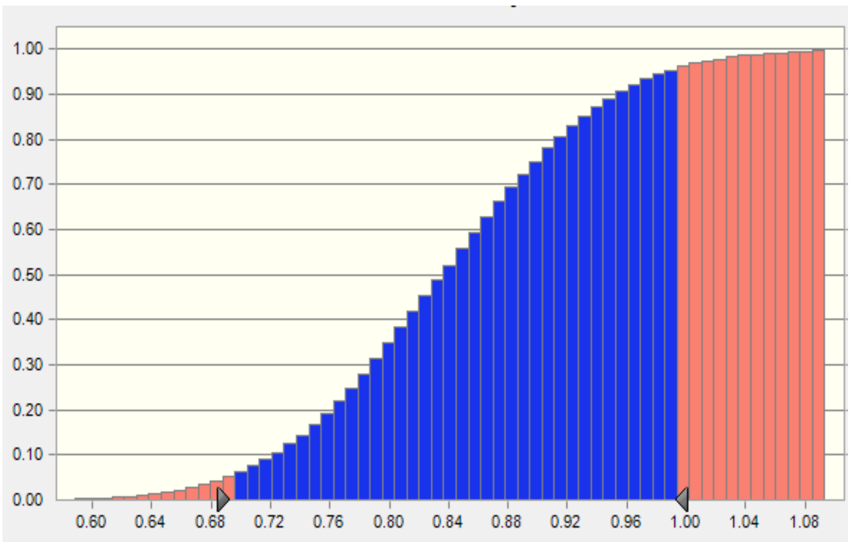

Figure 6D: Value of flexibility - Low Regime - NIGERIA

Expected value = 0.84$ /MMBtu.
Lower limit value (10%) = 0.69$ /MMBtu.
Upper limit value (90%) = 0.99$ /MMBtu.

Appendix E: Sensitivity to alternative threshold variables

Table 1E: LR test results based on the VXO stock market volatility threshold

Panel A: LR test for linearity against 2 regimes	
LR statistic	110.946
p-value	[0.000*]
Estimated threshold	25.12
Panel B: LR test for linearity against 3 regimes	
LR statistic	188.0672
p-value	[0.000*]
Estimated thresholds	24.33 28.01
Panel C: LR test for 2 regimes against 3 regimes	
LR statistic	77.121
p-value	[0.500]
Estimated threshold	24.33 28.01

Note: The response of LNG prices to changes in volatility context is supposed to occur with a delay *d* of 2 months. P-values based on Hansen's (1996) procedure method of inference with 500 replications are between brackets. *, ** denote the rejection of the null hypothesis at 1% and 5% respectively.

Table 4:

Table 2E: LR test results with volatility threshold based on daily oil price returns

Panel A: LR test for linearity against 2 regimes	
LR statistic	115.198
p-value	[0.000*]
Estimated threshold	0.0371
Panel B: LR test for linearity against 3 regimes	
LR statistic	257.086
p-value	[0.000*]
Estimated thresholds	0.0371 0.0447
Panel C: LR test for 2 regimes against 3 regimes	
LR statistic	141.888
p-value	[0.404]
Estimated threshold	0.0371 0.0447

Note: The response of LNG prices to changes in volatility context is supposed to occur with a delay *d* of 2 months. P-values based on Hansen's (1996) procedure method of inference with 500 replications are between brackets. *, ** denote the rejection of the null hypothesis at 1% and 5% respectively.

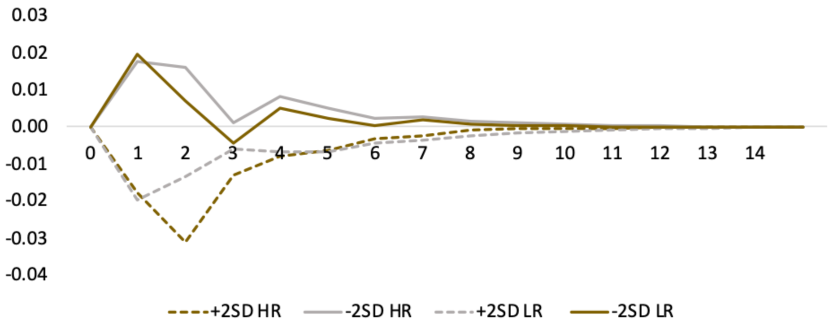

Figure 1E: JAP LNG response from oil price volatility* shocks of +/- 2 SD

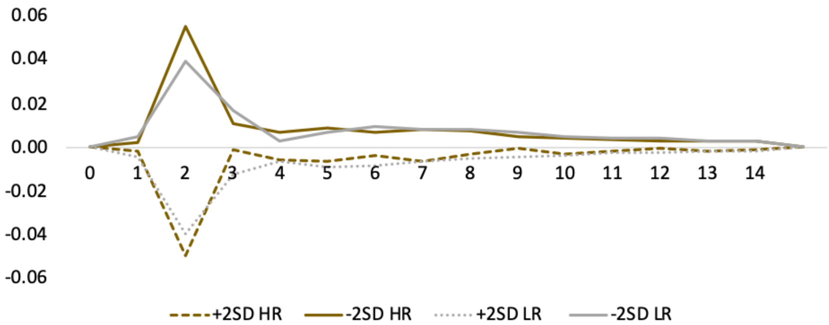

Figure 2E: US LNG response from oil price volatility shocks of +/- 2 SD

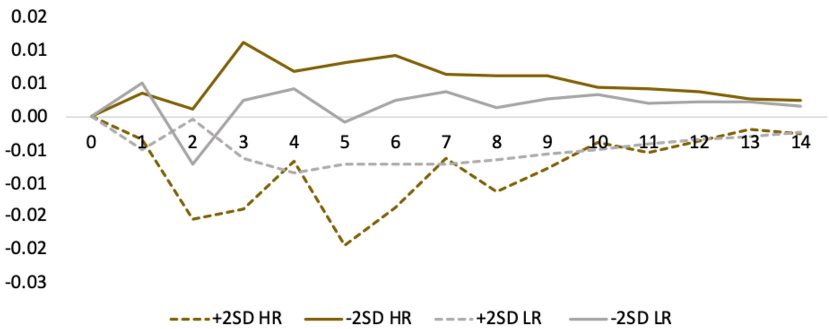

Figure 3E: EU LNG response from oil price volaility shocks of +/- 2 SD

Note: The x-axis corresponds to the months.
*: Oil price volatility calculation is based on **daily** oil price returns

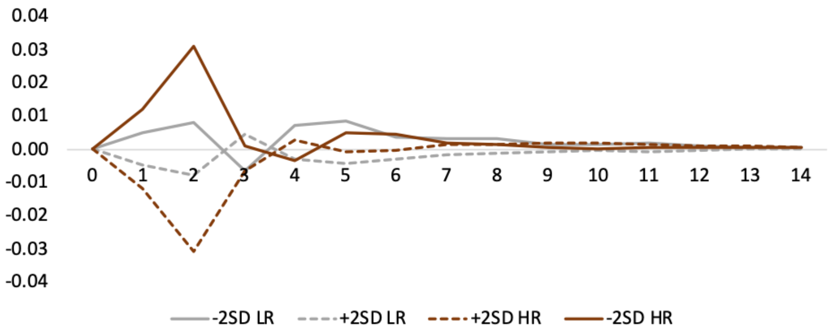

Figure 4E: JAP LNG response from CBOE VXO volatility shocks of +/- 2 SD

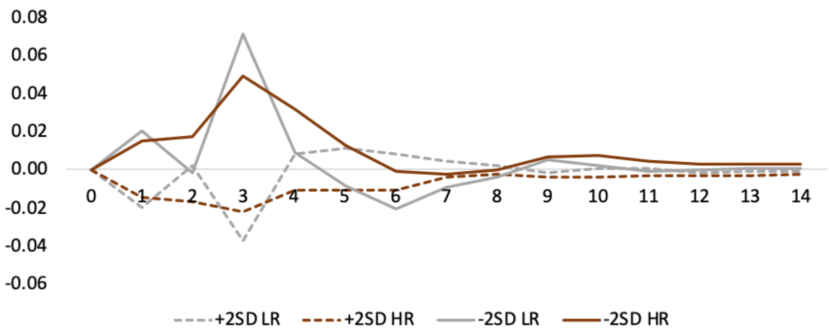

Figure 5E: US LNG response from CBOE VXO volatility shocks of +/- 2 SD

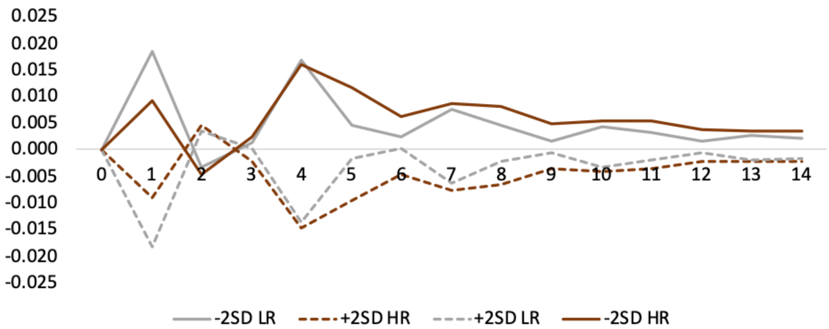

Figure 6E: EU LNG response from CBOE VXO volatility shocks of +/- 2 SD

Note: The x-axis corresponds to the months.

Appendix F: Robustness to different specifications of the TVAR model

Delay of the transition variable	Best Threshold Value	Wald Statistics		
		Sup-	*Avg-*	*Exp-*
1	0.02987	746.7516	712.2056	712.0976
		(0.000*)	(0.000*)	(0.000*)
2	0.03850	748.5684	706.8801	706.5793
		(0.000*)	(0.000*)	(0.000*)
3	0.04055	745.6221	705.5923	705.1586
		(0.000*)	(0.000*)	(0.000*)
4	0.02650	523.5905	523.5905	523.5905
		(0.000*)	(0.000*)	(0.000*)
5	0.02676	523.5905	523.5905	523.5905
		(0.000*)	(0.000*)	(0.000*)
6	0.02676	523.5905	523.5905	523.5905
		(0.000*)	(0.000*)	(0.000*)
7	0.02676	523.5905	523.5905	523.5905
		(0.000*)	(0.000*)	(0.000*)
8	0.02676	523.5905	523.5905	523.5905
		(0.000*)	(0.000*)	(0.000*)

Note: P-values based on Hansen's (1996) method of inference with 500 replciations are in parentheses. *,** denotes the rejection of the null hypothesis at 1 % and 5 % respectively.

Table 1F: Test for Threshold VAR for different delays of the transition variable.

Order of the MA process	Best Threshold Value	Wald Statistics		
		Sup-	*Avg-*	*Exp-*
1	0.04023	184.5802	145.3699	144.1165
		(0.570)	(0.482)	(0.482)
2	0.03888	559.6944	509.5040	508.8447
		(0.000)	(0.000)	(0.000)
3	0.03850	748.5684	706.8801	706.5793
		(0.000)	(0.000)	(0.000)
4	0.04067	961.8254	903.9336	903.3456
		(0.000)	(0.000)	(0.000)
5	0.03639	1031.256	992.858	992.476
		(0.000)	(0.000)	(0.000)
6	0.03887	1085.520	1048.393	1048.162
		(0.000)	(0.000)	(0.000)
7	0.03914	1165.940	1130.706	1130.492
		0.000	(0.000)	(0.000)
8	0.03707	1235.725	1196.078	1195.901
		(0.000)	(0.000)	(0.000)

Note: P-values based on Hansen's (1996) method of inference with 500 replciations are in parentheses. *,** denotes the rejection of the null hypothesis at 1 % and 5 % respectively.

Table 2F: Test for Threshold VAR for different orders of the moving average process of the threshold variable.

TVAR lags	Best Threshold Value	Wald Statistics		
		Sup-	*Avg-*	*Exp-*
1	0.02558	503.3623	503.3623	503.3623
		0.000*	0.000*	0.000*
2	0.03850	733.0622	687.4937	687.1522
		(0.000*)	(0.000*)	(0.000*)
3	0.03850	748.5684	706.8801	706.5793
		(0.000)	(0.000*)	(0.000*)
4	0.03850	799.9046	750.4848	750.2539
		(0.000)	(0.000*)	(0.000*)
5	0.03850	810.6776	764.8100	764.5587
		(0.000*)	(0.000*)	(0.000*)
6	0.03850	831.0653	789.2654	789.0786
		(0.000*)	(0.000*)	(0.000*)
7	0.03850	867.0831	827.2700	827.0429
		(0.000*)	(0.000*)	(0.000*)
8	0.03850	918.2078	863.4365	863.1159
		(0.000*)	(0.000*)	(0.000*)

Note: P-values based on Hansen's (1996) method of inference with 500 replciations are in parentheses. *,** denotes the rejection of the null hypothesis at 1 % and 5 % respectively.

Table 3F: Test for Threshold VAR for different lags of the VAR.

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