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# The Cool Spread: Hedging Natural Gas - LNG Price Movements

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### Abstract

The launch of liquified natural gas futures in May of 2017 on a major exchange follows a dramatic increase in global demand for the energy source. The profit of firms that produce LNG, known as transformers, is driven by the spread between the price of natural gas and LNG. With the launch of LNG futures, transformers now have the ability to hedge their exposure to this spread, similar to oil refiners hedging the crack spread. This paper proposes three hedging strategies transformers can utilize to limit their exposure to natural gas and LNG price movements. Using second-order lower partial moments (LPM2) as a measure for hedging effectiveness, this paper will show that transformers who do not hedge their exposure to the spread perform better than those who employ any of the proposed strategies, a result driven in part by 2017 market conditions.



### Keywords

natural gas, LNG, commodity hedging

### Disciplines

Business

# THE COOL SPREAD: HEDGING NATURAL GAS – LNG PRICE MOVEMENTS

By

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**ABSTRACT**

The launch of liquified natural gas futures in May of 2017 on a major exchange follows a dramatic increase in global demand for the energy source. The profit of firms that produce LNG, known as transformers, is driven by the spread between the price of natural gas and LNG. With the launch of LNG futures, transformers now have the ability to hedge their exposure to this spread, similar to oil refiners hedging the crack spread. This paper proposes three hedging strategies transformers can utilize to limit their exposure to natural gas and LNG price movements. Using second-order lower partial moments ($LPM_2$) as a measure for hedging effectiveness, this paper will show that transformers who do not hedge their exposure to the spread perform better than those who employ any of the proposed strategies, a result driven in part by 2017 market conditions.

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# INTRODUCTION

While LNG has existed as an energy source for over 70 years, it has not been widely used as the costs inherit in producing it were prohibitive. However, recent technological advancements and depressed natural gas prices have made LNG a viable global energy source. The launch of LNG futures contracts on the Intercontinental Exchange give transformers the ability to hedge their exposure to LNG price volatility using exchange traded financial instruments for the first time. Drawing on the crack spread for inspiration, this paper proposes three hedging strategies that take into account production time and the various inputs/outputs associated with the transformation of natural gas into LNG. This study utilizes $LPM_2$ to measure hedging effectiveness as, unlike the more commonly used minimum variance statistic, it only penalizes downside deviations of a hedging strategy. Thus, $LPM_2$ better captures the risk profile of transformers who prefer hedging strategies that are allowed to deviate from market prices if it means an increase in profit. While the results of this paper are limited by the available data, it discusses the necessary framework in depth required to analyze the relatively new LNG industry for future researchers.

## Natural Gas Overview

Natural gas is a fossil fuel used mostly to generate electricity, produce various chemical products, and to heat homes. The price of natural gas is quoted per million British thermal units (MMBtu), with a single Btu defined as the amount of energy required to heat one pound of water by one degree Fahrenheit. In the United States, the natural gas benchmark price is quoted from the Henry Hub, a distribution center in Louisiana. Natural gas prices across the United States are conventionally quoted by a spread above or below the price at the Henry Hub. The fossil fuel currently accounts for approximately 24% of the world's total energy consumption, a figure that stood at 16% in 1973 (BP, 2016).

Natural gas can be categorized as either wet or dry depending on its composition. Dry gas is primarily composed of methane while wet gas is made up of compounds such as ethane and propane in addition to methane. These additional compounds are known as natural gas liquids (NGLs) and when wet natural gas is treated, the compounds can be separated and sold commercially. As natural gas prices have reached historic lows recently, wet gas is considered more valuable than dry gas because NGLs can be sold at a higher price per MMBtu than natural gas. Wet natural gas is generally found in shale formations, the target of frackers drilling for crude oil. Wet gas is composed of roughly 80% methane, with ethane and propane making up the vast majority of the remaining percentage. For comparison, processed natural gas is approximately 90% methane and 10% ethane (NAESB, 2003). In 2017, the U.S. produced 28.8 trillion cubic feet of wet gas, which directly resulted in the production of 952.6 million barrels of ethane and propane (EIA, 2018).

The growth of natural gas as a global energy source is driven primarily by two factors. First, it is considered the cleanest of all fossil fuels, especially compared to the closest comparable fossil fuel used to generate power, coal. This has become particularly important as countries around the world seek to reduce their carbon emissions and improve air quality. The second factor that helps to explain natural gas's growth is price. Natural gas is significantly cheaper than coal with respects to energy production. According to a report from Lazard, in 2017 the estimated levelized cost of one megawatt hour (mWh) of electricity generated by coal costs $102. In comparison, one mWh generated by natural gas costs just $60 (Ailworth, 2017). The advent of fracking has driven natural gas prices to historic lows as natural gas is released as a byproduct of the drilling technique. Fracking has brought what were once previously inaccessible natural gas reserves to the market.

The infrastructure required to transport natural gas has long been its greatest drawback. Natural gas can only be used in locations that are connected to a pipeline, a problem particularly relevant for countries without their own natural gas reserves and without pipeline infrastructure (e.g. Japan). Such countries have needed to rely on renewables or coal, which can easily be shipped around the world, to generate power. However, recent technological developments have made LNG a viable option for countries who find themselves unable to import natural gas.

**The Development of LNG**

LNG is produced by cooling natural gas to -260°F, the temperature at which natural gas exists as a liquid. It is then loaded onto specialized cargo ships and sent to its destination port, where it is regasified and delivered to its final destination via natural gas pipelines. Firms that produce and regasify LNG are known as transformers, the equivalent of oil refiners for LNG. The ability to liquify natural gas has the clear benefit of providing natural gas to countries who previously had no access to the energy source. In addition, transporting natural gas in its liquified form results in less carbon emissions than traditional pipeline transportation, furthering the energy source's reputation as the cleanest fossil fuel available (IGU, 2015).

However, the costs associated with transforming LNG are significant. Terminals that transform natural gas to LNG must be built on ports that can be accessed by tankers and require significant investment to construct, generally over $1 billion. Furthermore, LNG can only be shipped on certain specially equipped tankers, that cost a minimum of $300 million to build. LNG must be shipped to ports with regassification capabilities, which also require significant investment. In addition, because LNG must be cooled and stored at -260°F utility costs are significant, representing 20% of all operational costs of an LNG terminal (Carroll, 2017).

However technological improvements coupled with growing global demand for natural gas has made LNG a viable energy source despite the costs associated with it. These market conditions have led to a number of developments within the LNG market. In February of 2017, China signed a deal with the United States to import 1.2 million tons of LNG per year from 2023 to 2043 (Matthews, 2018). Currently, there are three active LNG export terminals in the U.S., with the Sabine Pass facility in Louisiana accounting for 75% of total liquefication capacities and is not yet fully operational. Five other LNG export terminals are currently under construction with four more sites recently being approved by regulators. The total capacity of all projects either under construction or approved would increase the U.S. output to 401.8 million tons per annum (mtpa), dwarfing current U.S. production of 9 mtpa (Carroll, 2017).

Perhaps the most significant development in the LNG market for purposes of this paper is the launch of LNG futures contracts. On May 4, 2017, the Intercontinental Exchange launched the first ever LNG futures contract benchmarked to the Gulf Coast price of LNG in the U.S. The launch of an LNG futures contract now allows firms to hedge their risk to LNG price movements they could only previously do with the use of forward contracts. The liquid nature of futures contracts also allows commodity traders to take positions in LNG that were once impossible. But most importantly, it allows transformers to hedge their exposure to the difference between the price of natural gas and LNG, much like refiners do with oil and its refined products.

**The Crack Spread**

Cracking is the process in which the carbon-carbon bonds of complex organic molecules are broken to create simpler molecules (Alfke et al., 2007). This is the process refiners use to transform crude oil into its refined products such as gasoline, heating oil, and jet fuel. The difference between the price of crude oil and the price of its refined products is thus known as the crack spread. In the United States, the crack spread is calculated as follows:

$$Crack\ Spread = \frac{2\ \times\ RB\ +\ HO - 3\ \times CL}{3} \tag{1}$$

Where each variable represents the price per barrel of the following commodities:

*RB = RBOB Gasoline*

*HO = New York Harbor ULSD Heating Oil*

*CL = WTI Crude Oil*

The proportions are meant to mimic the approximate output of three barrels of light, sweet crude oil as it passes through a refiner. In other words, for every three barrels of light, sweet crude oil that is cracked, a refiner produces roughly one barrel of heating oil and two barrels of gasoline, which is why the crack spread is frequently referred to as the “3:2:1.” There are a number of variations on the crack spread, such as the 5:3:2 and the 1:1 (which is just the difference in price between gasoline and crude oil), but the most commonly quoted crack spread is the 3:2:1 (EIA, 2013).

The ability to hedge the crack spread using futures contracts is of particular importance to oil refiners. Unlike drillers and airlines, who are only impacted by movements on one side of the crack spread, refiners face the challenge of being impacted by both. By definition, a refiner’s profitability is driven by the difference between the price it can sell oil’s refined products for and the cost of purchasing crude oil to refine, i.e. the crack spread. Refiner’s demand for protection from crack spread volatility has made the bundle of futures contracts that make it up one of the most commonly traded combinations in the world (Liu, et al., 2017). With the launch of LNG futures, natural gas transformers who face the same problem as refiners, can now hedge their exposure to the natural gas equivalent of the crack spread.

## RESEARCH QUESTION

With the introduction of ICE's LNG futures contract in May 2017 came the opportunity for natural gas transformers to hedge their exposure to the spread between natural gas and LNG prices using exchange traded securities. The most relevant research question for transformers asks what is the most effective way to hedge the difference in prices of natural gas and LNG? However, this question is beyond the scope of this paper due to the advanced technical nature of the topic and the resources needed to fully address it. Instead, this paper proposes three different combinations of futures contracts meant to mimic this spread and asks of these hedging strategies, which one most effectively hedges transformer's risk to the natural gas-LNG spread?

Luckily, one question that does not need further research is what to call this difference in prices? While natural gas is not cracked, it does need to be cooled to -260°F to be converted to LNG. Thus, the difference in prices between LNG and natural gas will be referred to as the cool spread throughout the paper (Huemmler, 2017).

## SIGNFICANCE

If the crack spread's importance to the oil industry is any indicator, the cool spread has the potential to become a commonly accepted indicator of market conditions for both natural gas and LNG, especially if the forecasted growth of global demand for LNG materializes. Effective hedging of the cool spread will be of particular significance to transformers, institutional market makers, and commodity traders. These three groups are discussed below.

**Transformers**

The cool spread is a key driver of transformer's operating margin, much in the same way the crack spread is for oil refiners. Transformers have a vested interest in securing a stable operating margin, which can be accomplished through efficient cool spread hedging. This allows transformers to focus on issues they can control, optimization of export terminals, and insulate them from those issues they cannot, global commodity prices. As more export terminals are approved by regulators and begin operations, the demand for financial instruments to hedge the cool spread will increase.

**Market Makers**

Transformers will not enter into futures contracts independently, they will most likely purchase the instruments through a financial intermediary, such as a market maker. Large financial institutions such as Goldman Sachs and Morgan Stanley compete for fees that come with advising clients in complex financial situations, such as what transformers face in determining their hedging strategy. Naturally, these market makers will have an interest in designing efficient hedging strategies to attract and keep transformers as clients. Knowing what bundle of futures best insulates transformers from volatility in the cool spread will be crucial to attracting them as clients.

**Commodity Traders**

The development of the cool spread will provide new opportunities for speculation, which makes the bundles of futures contracts that make it up of particular interest to day traders. While these traders will not have any interest in the rationale behind the use of certain financial instruments to hedge the cool spread, they will care what contracts transformers decide to use.

Traders will want to position themselves to take advantage of the increased trading volume and open interest, a position that will be dictated by the futures transformers use to execute their hedge. Day traders commonly position themselves to take advantage of movements in the crack spread and there is no indication that the cool spread would be any different, especially considering natural gas futures are the second most traded energy commodity on the CME.

## LITERATURE REVIEW

As this paper seeks to compare the effectiveness of various hedging strategies revolving around natural gas and LNG futures, relevant literature includes LNG market dynamics, established natural gas hedging strategies, and hedging efficiency measurements. These three topics are discussed below.

### LNG Market

Fifteen years ago, the LNG market was dominated by rigid long-term contracts between governments, especially in Asia. Suppliers used rigid such contracts with significant price premiums and take-or-pay clauses to guarantee financing for LNG terminals. End consumers were willing to take on contracts with such unfavorable terms in order to guarantee a supply of natural gas (Choi, Heo, 2017). Due to the rigid nature of these contracts LNG tankers were referred to as floating pipelines to reflect the economic reality that such contracts mirrored pipeline contracts for natural gas, which notoriously lack flexibility (Ponce, Krone, 2014). The lack of a benchmark natural gas price in Asia meant the price of LNG was often tied to the price of crude oil (Stern, 2012).

The desire for energy independence, driven by European tensions with Russia, one of the world's largest natural gas suppliers, coupled with stricter global emissions standards have driven the construction of new LNG terminals in the Baltic States (Serry, 2017). As these European terminals have gone online, Asia's largest LNG supplier, Qatar, has begun to export LNG to Europe. The result is LNG prices in Asia are increasingly tied to demand for natural gas in Europe, and thus tied to European benchmark natural gas prices (Rozmarynowska, 2012). As the U.S. continues to expand its LNG production capabilities, the market for LNG more closely resembles that of the oil market instead of a floating pipeline (Bernstein et al., 2016).

**Natural Gas Hedging**

The use of natural gas futures to hedge exposure to fluctuations in the underlying's spot price is not as effective as other energy futures such as oil, gasoline, and heating oil. This effect is magnified during low probability tail events, such as particularly severe hurricanes. This inefficiency is driven by natural gas's limited export capabilities in comparison to other energy sources and difficulties in storage and transport (Hanly, 2017). Pipeline infrastructure in the United States suffers from regional segmentation, a problem other energy sources do not have as they can be transported via rail and trucks. Due to the reliance on pipelines, regional natural gas prices vary dramatically because of the transport capacity of each pipeline and abnormal transportation pricing (e.g. it may be cheaper to transport natural gas between two primary hubs that are considerable distance apart compared to two secondary hubs that are much closer together). As a result, natural gas futures can hedge movements in spot prices more effectively for regions connected via pipeline infrastructure to the Henry Hub, such as the East Coast, Midwest, and Southeast compared to those regions that are not, the Rockies and West Coast (Brinkman, Rabinovich, 1995).

However, recent studies have suggested strategies that the use of natural gas futures to hedge changes in spot prices can be made more efficient. For example, adjusting hedging ratios to account for seasonal fluctuations in the natural gas market can improve hedging effectiveness. This fact holds true regardless of the length of the hedging period (Martinez, Torro, 2015). The hedging effectiveness of natural gas futures can be further improved using a non-matching hedging strategy that varies the maturity of natural gas futures beyond the hedging horizon (Ghoddusi, Emamzadehfard, 2017). In addition, improved pipeline infrastructure coupled with the existence of natural gas basis swaps contracts has resulted in regional spot prices in California moving in tandem with spot prices at the Henry Hub (Woo et al., 2006).

**Efficient Hedging**

Conventional wisdom suggests that minimum variance is an appropriate measure of hedging effectiveness in energy markets due to the volatile nature of energy prices and ease of use when estimating hedge ratios (Alexander et al., 2013). However, observed hedge ratios often differ significantly from the efficient hedge ratios implied by minimum variance calculations, suggesting minimum variance calculations do not accurately reflect hedgers underlying concerns (Collins, 1997; Egeland et al., 2013). Recent research suggests that in scenarios that require multi-commodity hedging, the use of minimum variance hedging offers no meaningful reduction in risk criterion (Alexander et al., 2013). When $LPM_2$ is used to calculate optimal hedging ratios in multi-commodity scenarios hedging ratios are smaller than those computed by minimum variance (Power, Vedenov, 2009). Numerous researchers have proposed using second-order lower partial moments ($LPM_2$) instead of minimum variance to measure hedging effectiveness (Liu et al., 2017; Collins, 2000; Unsher, 2000). Thus, $LPM_2$ more accurately measures the risk profile of certain commodity hedgers, such as refiners, who are only concerned with downside protection (Liu et al., 2017). Furthermore, $LPM_2$ is calculated using a given reference level (e.g. expected profits without hedging) which allows for flexibility to adjust for a hedgers risk profile (Mattos et al., 2008).

## METHODOLOGY

The methodology for this paper can be divided into three steps. It begins with designing multiple combinations of futures meant to mimic the cool spread. The next step becomes collecting all relevant price information for these bundles to determine the profitability of each hedging strategy. Finally, this paper calculates and compares the $LPM_2$ of each hedging strategy as a proxy for hedging effectiveness, with the average profit earned without hedging over the period in question serving as the reference level in the calculation of $LPM_2$.

### Designing Hedging Bundles

This paper draws on commonly traded futures bundles that mimic the crack spread for inspiration in designing hedging strategies meant to insulate LNG transformers from price movement in the cool spread. When deciding what securities to incorporate in each hedging bundle, this paper only considers futures contracts. The price visibility and low transaction costs associated with futures contracts makes the securities an attractive option for any hedging scenario. Thus all proposed bundles will exclusively utilize futures as a financial instrument for hedging. Only when the data for a pertinent futures contract is unavailable will other financial instruments be considered. The factors to consider in each hedging strategy are limited to the underlying asset of the futures contract, the position in the futures contract (i.e. long or short), the quantity of futures contracts bought or sold, and the maturity of the contracts. When considering which underlying assets to use in a hedging strategy, this paper considers the inputs required for producing LNG and the composition of the natural gas being liquefied, which affects the byproducts of liquefaction and treatment. Whether a given commodity is an input or output with respects to LNG production will determine the long or short position in the corresponding futures contract for all hedging strategies. Long positions will represent inputs and short positions will represent outputs. The number of contracts bought or sold will be based on quantities of inputs needed and outputs generated from the liquefaction process. The ratio of contracts entered into for a given strategy will be referred to as the hedging ratio, *h*.

Once the strategies are designed, the paper will calculate the profit *π(h)* for each hedging bundle using historical price data. The spot price, *S*, future price, *F*, at the beginning of the hedge timeline, t=0, and end, t=1, of every commodity represented in the hedging strategies will be used in conjunction with the chosen hedge ratio, to compute the profit of the hedging strategy over the period of analysis. For example, using this framework the profit earned from hedging the crack spread with the 3:2:1 over a given period can be stated as:

$$\pi(h^{3:2:1}) = \frac{2}{3}S_1^{GAS} + \frac{1}{3}S_1^{HO} - S_0^{OIL} + (F_1^{OIL} - F_0^{OIL}) + \frac{2}{3}(F_0^{GAS} - F_1^{GAS}) + \frac{1}{3}(F_0^{HO} - F_1^{HO}) \quad (2)$$

With the coefficient of each term representing that commodities hedge ratio (i.e. $h^{GAS}=\frac{2}{3}$). The hedging ratio of each bundle this paper proposes is fixed. In reality, this is not always the case, however all commonly utilized crack spread hedges employ a fixed hedge ratio and this paper utilizes that framework to simplify the analysis (Liu et al., 2017). The following trading strategies will serve as the basis for comparison in this paper.

***Naked (No Hedging)***

This will be the base case, with the average profit earned from a naked position serving as the reference level when calculating the $LPM_2$ of the hedging bundles listed below. Profit earned from naked hedging will be defined as:

$$\pi(h^0) = S_1^{LNG} - S_0^{NG} \tag{3}$$

Note that this differs from the cool spread in that it takes into account the hedging timeline, which is discussed in more detail below. The cool spread is calculated using spot price data when $t_0=t_1$.

***Naïve Hedge (The 1:1)***

A naïve hedge refers to any situation in which a hedger uses derivative instruments with the same underlying asset as the asset being hedged. The hedging ratio is set to equal the exposure of the hedger to the asset in question. Naïve hedging is a commonly employed strategy to hedge the crack spread, with hedgers purchasing one crude oil future for every gasoline future they short. A naïve hedge with respects to the cool spread is quite similar to its crack spread equivalent, with $h^{LNG} = h^{NG} = 1$. Profit earned from the naïve hedge position is as follows:

$$\pi(h^n) = S_1^{LNG} - S_0^{NG} + (F_1^{NG} - F_0^{NG}) + (F_0^{LNG} - F_1^{LNG}) \tag{4}$$

***NGL Hedge***

The NGL hedge will assume the natural gas being liquefied is wet, thus resulting in the production of NGLs while the wet gas is treated before liquefication. Using wet gas production data from the U.S. Department of Energy and natural gas chemical composition data from the National American Energy Standards Board, the hedging ratio will be set as $h^{LNG} = \frac{16}{20}$; $h^{NG} = 1$; $h^{ETH} = h^{PRP} = \frac{3}{20}$. The calculations of these ratios can be found in Appendix A. Profit earned from the NGL hedge position is as follows

$$\pi(h^{NGL}) = \frac{16}{20}S_1^{LNG} + \frac{3}{20}S_1^{ETH} + \frac{3}{20}S_1^{PRP} - S_0^{NG} + (F_1^{NG} - F_0^{NG}) + \frac{16}{20}(F_0^{LNG} - F_1^{LNG}) + \frac{3}{20}(F_0^{ETH} - F_1^{LNG}) + \frac{3}{20}(F_0^{PRP} - F_1^{PRP}) \quad (5)$$

***Power Hedge***

This hedge adds electricity futures contracts as an input to the naïve hedge strategy outlined above. Utility costs associated with power represent a large proportion of the total cost of production of LNG. Based on academic literature related to the electricity costs associated with LNG, this paper assumes 400 kilowatt hours (kWh) are required to produce one ton of LNG (Dhameliya, Agrawal, 2016). Converting kWh/ton to mWh/MMBtu leads to a hedge ratio of $h^{LNG} = h^{NG} = 1$; $h^{ELC} = \frac{2}{250}$. Profit earned from the naïve hedge with electricity is as follows:

$$\pi(h^{POW}) = S_1^{LNG} - S_0^{NG} - \frac{2}{250}S_0^{ELC} + (F_1^{NG} - F_0^{NG}) + (F_0^{LNG} - F_1^{LNG}) + \frac{2}{250}(F_1^{ELC} - F_0^{ELC}) \quad (6)$$

The hedging ratio of electricity futures being so close to zero reflects the convention of quoting electricity futures in dollars per mWh, a measurement of power much larger than the heat energy measurement equivalent used in quoting natural gas prices.

**Data**

Expected profit calculations of the aforementioned hedging bundles require spot and future price data of all aforementioned commodities. The period this paper examines begins May 4th, 2017, when ICE launched its LNG futures contract, to May 2, 2018. The source of the price data for these variables is as follows:

- Natural Gas Spot Price- Henry Hub daily prices
- Liquefied Natural Gas Spot Price- North Asian Singapore Exchange Limited LNG Index Group (SLING). The Sling is an index that estimates LNG spot prices in China, Korea, Japan, and Taiwan by polling asking participants in the Asian LNG market (brokers, transformers, buyers, etc.) what they believe is a “fair price” for LNG in the aforementioned countries. The Sling is calculated every Monday and Thursday and is calculated using a similar methodology as LIBOR (EMC, 2017)
- Propane Spot Price- North American Spot LPG Price/Mont Belvieu. Mont Belvieu is home to Lone Star Gas’s storage facility and functions as the U.S. benchmark for propane prices
- Ethane Spot- NYMEX Mont Belvieu Ethane 5 Decimal (OPIS) Swap
- MISO Spot- Midwest ISO Indiana Hub Hourly Day Ahead Off-Peak Averages. MISO refers to the Independent System Operator that provides power to much of the Midwest and certain Southern states. It is headquartered in Indiana
- Natural Gas Futures- NYMEX Henry Hub Natural Gas
- Liquefied Natural Gas Futures- LNG Japan/Korea Marker (Platts) Swap
- Propane Futures- NYMEX Mont Belvieu LDH Propane
- Ethane Future- North American Purity Ethane Spot Price/Mont Belvieu non-LST
- MISO Future- NFX MISO Indiana Hub Real-Time Off-Peak Financial Futures

All price data was downloaded from a Bloomberg terminal with the exception of Henry Hub natural gas spot prices, which is from the EIA.

The use of the aforementioned price sources was driven in part by design and in part by necessity. The decision to source all natural gas price data from the Henry Hub in all hedging strategies reflects its importance as a global benchmark for U.S. natural gas and its proximity to the Sabine Pass, the largest operational LNG export terminal in the U.S. The study utilizes MISO futures contracts for power because the Sabine Pass is located in the region served by MISO. The use of Asian LNG prices is driven more out of necessity. The only resource available to Wharton students that has any data on LNG pricing is Bloomberg, which only quotes Asian spot and futures prices. S&P Global Platts publishes global daily LNG price data (the NYMEX LNG swap used as a proxy for a future uses Platts to price the underlying LNG), but it is not available to retail investors or researchers. However, the use of Asian LNG price data is not necessarily an inaccurate situation. In 2017, roughly half of all LNG the U.S. exported was sent to Asia. The decoupling of Henry Hub natural gas and crude oil prices, to which LNG prices are indexed to in Asia, has driven demand for U.S. LNG to record highs. In 2016 the U.S. exported approximately 150 million cubic feet of LNG per day to Asia. In 2017 that figure reached 900 million, reflecting the attractiveness of U.S. LNG to Asian consumers. Furthermore, the U.S. sells 60% of its LNG on the spot market. Even most of the U.S.'s long-term LNG contracts contain clauses that allow the LNG to be rerouted anywhere in the world under certain conditions (EIA, 2018). Thus, the use of Asian spot prices in calculating transformer profits is representative of current market conditions.

**Hedging Timeline**

In order to accurately reflect the situation a U.S. transformer faces given the available data, the hedging timeline will reflect the transportation time of natural gas from the Permian Basin to the Sabine Pass and then to Asia. The result is a hedging timeline of three weeks, based on the following calculations. Assuming the transformer's facility is the Sabine Pass, based on the significant percentage it contributes to total U.S. LNG exports, and the natural gas feedstock used originates in the Permian Basin, based on the natural gas production data and pipeline infrastructure, the natural gas will travel approximately 500 miles before reaching the Sabine Pass.

Natural gas travels through pipelines at speeds ranging from 10-20 mph depending on the proximity of the nearest compressor station along the pipeline (INGAA, 2018). Assuming a constant rate of 15 mph, it will take the natural gas approximately one day to arrive at the Sabine Pass after it has been purchased.

Very little literature exists with respects to the time needed to transform natural gas into LNG. However, there is data that discusses the amount of time needed to load LNG onto carries, which can take up to an entire day. This paper makes the simplifying assumption that the Sabine Pass is not capacity constrained such that once the feedstock natural gas arrives at the terminal it is liquefied and loaded onto a carrier within one day.

As soon as the LNG is loaded onto a carrier, the paper assumes it is transported to an Asian port based on U.S. export data and publicly available price information. For simplicity, Tokyo is used as the final destination for the LNG due to the country's growing demand for U.S. LNG and the paper's use of Japanese LNG swap contracts. Estimates from the Oxford Institute of Energy Studies show LNG carriers can travel at 19 knots, regardless of whether they use a steam turbine or dual fuel diesel electric propulsion system (Rodgers, 2018). Tokyo is 9,200 nautical miles from the Sabine Pass, a journey that would last 20 days at speeds of 19 knots. Upon arrival, the LNG would be sold on the spot market in Tokyo.

In aggregation, this scenario assumes that after natural gas feedstock has been purchased by a transformer, it will be sold as LNG 22 days later, representing the hedging timeline. This paper uses a hedging timeline of 21 days, or three weeks, to simplify the trading dates. In summary, when calculating hedging strategy profits, t=0 corresponds to the date natural gas feedstock is purchased and t=1 corresponds to the date three weeks later. The transformer would enter into a short futures position for all outputs and a long futures position for all inputs at t=0. At t=1, the transformer would cover its short positions and exit the long position. At no point would the transformer ever take delivery of the underlying commodity.

**Active Trading Month**

With the three-week hedging timeline in mind, the next consideration becomes what month to trade of each futures contract. Generally speaking, the prompt month is also the active month in futures trading. As such, this paper uses the prompt month with respects to the actual dates in the three-week hedging timeline. While the various futures contracts employed have differing last days of trading, NYMEX Henry Hub futures cease trading the earliest in the month of all relevant futures contracts at three trading days before first trading day of the delivery month. For example, June 2018 NYMEX Henry Hub futures stop trading on May 29th, 2018, three trading days before June 1st. To ensure margin requirements do not become burdensome and the prompt month contract remains liquid, this paper switches trading months three days before the natural gas futures cease trading. This practice is in line with crack spread trading, where hedgers and speculators alike cease trading the crack spread of a given month anywhere from seven to three trading days before the contract officially ceases trading. To continue the above example, June trading of the cool spread would cease on May 24th, three trading days before the contract expires. Here May 24th would represent t=1, the date the transformer exits all futures positions, and May 3rd would be t=0 to make the hedging horizon three weeks.

This paper elects not to roll hedges into the next month if a given date's hedging timeline coincides with the expiration of natural gas contracts and instead moves the active month to the month following the prompt. A common strategy used by hedgers and traders alike is to roll their futures position into the next month at the expiration date. Instead of completely exiting their futures position, the trader or hedger would exit their positions in the prompt month and convert them to the same position in the active month. In comparison, if the expiration of the prompt month's contract occurs during the hedging horizon, this paper switches trading to the following month to avoid having to roll the contracts. Recent literature suggests the practice of automatically rolling a series of futures "creates a saw-tooth pattern in the basis," a driving factor in this paper's decision avoid the rollover strategy when collecting price data (Nguyen et al., 2017).

**Comparing Hedging Strategies Using $LPM_2$**

In order to more accurately portray the risk profile of transformers, this paper uses $LPM_2$ as a measurement for hedging effectiveness. As described in the literature review of efficient hedging, $LPM_2$ better reflects the hedging preferences of transformers as it only penalizes downside deviations from a reference level while minimum variance penalizes upside and downside deviations equally. In other words, $LPM_2$ would not penalize a hedging strategy that resulted in a larger profit for transformers than they would have earned without hedging, while minimum variance would. $LPM_2$ is defined as:

$$LPM_2 = \int_{-\infty}^{\bar{X}} (\bar{X} - X)^2 dF(X) \tag{7}$$

Where X is a random variable of interest, $\bar{X}$ is a chosen reference level, and F(X) is the cumulative distribution function of the random variable of interest X. This paper uses the profit earned by a given hedging strategy as X and the average profit earned by a transformer without hedging during the period of observation as the reference level $\bar{X}$. By using average profit earned by a transformer without hedging as the reference level, this paper's $LPM_2$ calculation only penalizes hedges that earn a profit below the average profit without hedging.

In order to actually calculate $LPM_2$ for a hedging strategy, a given hedging strategy's profits over the period of observation will be plotted in a histogram. The next step involves calculating the function within the above integral for each bin in the histogram below the reference level. From there, the Riemann sum will be calculated from the tail of the cumulative distribution function to the reference level. The Riemann sums will be weighted to account for the size of each bin relative to the total observed trading days. The solution to this integration gives the $LPM_2$ statistic for the hedging strategy in question and serves as the basis for comparing each strategy's effectiveness given the transformer's risk profile.

## HYPOTHESIS

Drawing on prior research cited in the literature review above and knowledge of the process of natural gas liquefication, this paper's initial hypothesis states the naïve hedge will be the most effective proposed hedging strategy because it most closely mirrors actual inputs and outputs transformers face. A hedge ratio of 1:1 reflects the relatively small quantities of impurities removed from natural gas prior to the liquefication process, regardless of the grade of natural gas used as feedstock by the transformer.

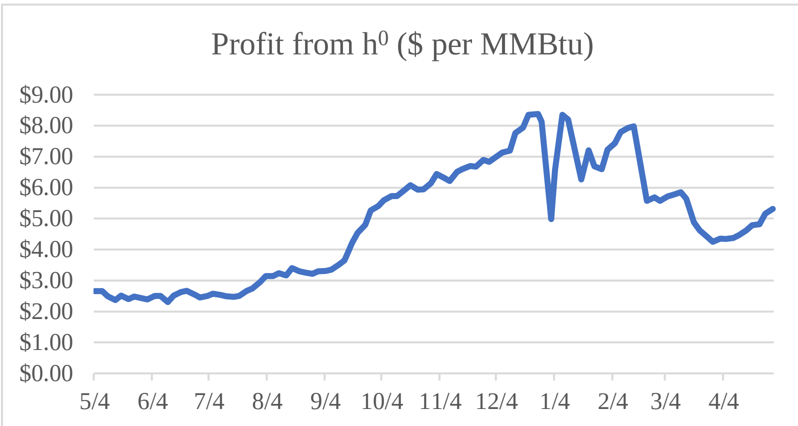
## RESULTS

This paper relies on one year of trading data from May 2017 to May 2018. After accounting for limited LNG daily spot price data points available from the SLING (roughly two data points per five trading days) and the removal of data points in which the hedge start or end date falls on a trading holiday, this study contains 87 observations per trading strategy. In calculating $LPM_2$ this paper uses bin widths of $0.10 for the construction of histograms of realized profits for each of the hedging strategy. The midpoint rule is utilized when calculating the Riemann sum to determine $LPM_2$.

**No Hedging**

Profit earned without any hedging strategy contains 93 observations, more than each hedging strategy due to the availability of spot price data on trading holidays in which futures prices are unavailable. Exhibit 1 displays the profit earned by transformers that do not implement a hedging strategy.

Exhibit 1: Profit Earned without Hedging




The average profit earned without hedging is $5.21 per MMBtu, which will serve as the reference level when calculating $LPM_2$. The $LPM_2$ was calculated for the no hedging strategy in the same manner as all hedging strategies. The $LPM_2$ of the transformer that does not hedge is 0.1757. 44 of the 93 observations resulted in a profit below the reference level. The $LPM_2$ of the no hedging strategy will serve as the benchmark for the other hedging strategies.

**Naïve Hedging Strategy**

The average profit earned using the naïve hedging strategy is $4.93 per MMBtu. Exhibit 2 displays the profit earned by transformers that implement the naïve hedging strategy and Exhibit 3 displays the profit earned above or below a no hedging strategy over the period of observation.

Exhibit 2: Profit earned with the Naïve Hedging Strategy

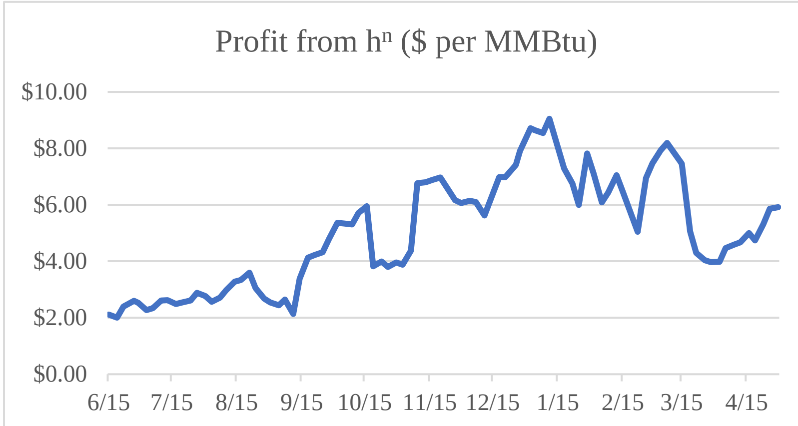
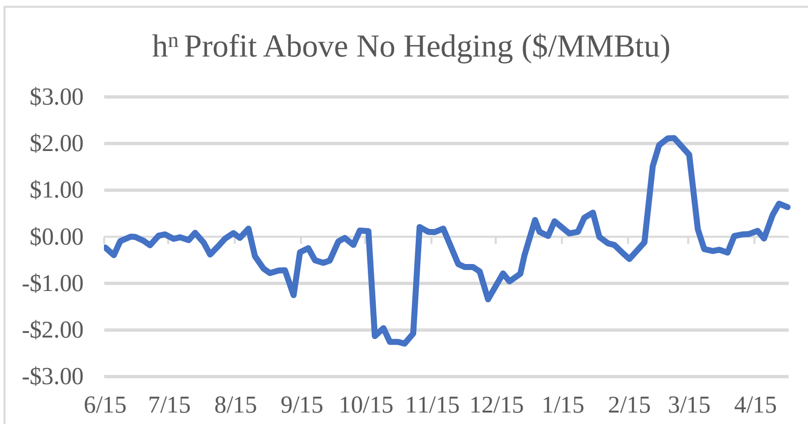



Exhibit 3: Naïve Hedging Profit Above the No Hedging Strategy




Using bin widths of $0.10 in calculating the weighted Riemann sum leads to the creation of 27 unique bins. The $LPM_2$ of the naïve hedging strategy is 0.2277. 48 of the 87 observations resulted in a profit below the reference level.

**NGL Hedging Strategy**

The average profit earned using the NGL hedging strategy is $3.28 per MMBtu. Exhibit 4 displays the profit earned by transformers that implement the NGL hedging strategy and Exhibit 5 displays the profit earned above or below a no hedging strategy over the period of observation.

Exhibit 4: Profit earned with the NGL Hedging Strategy

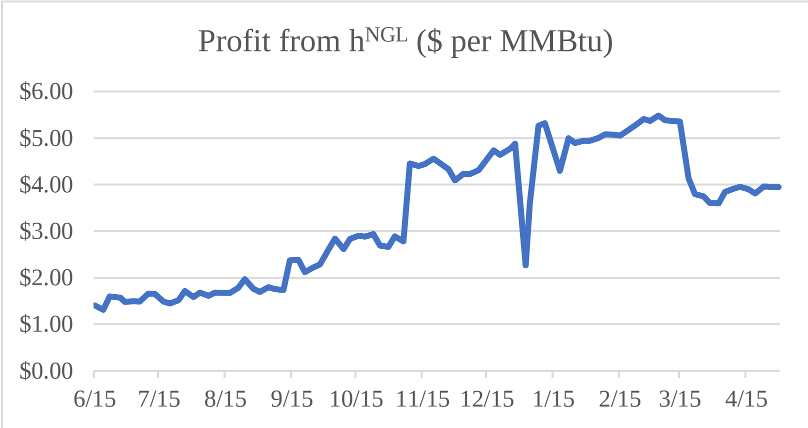
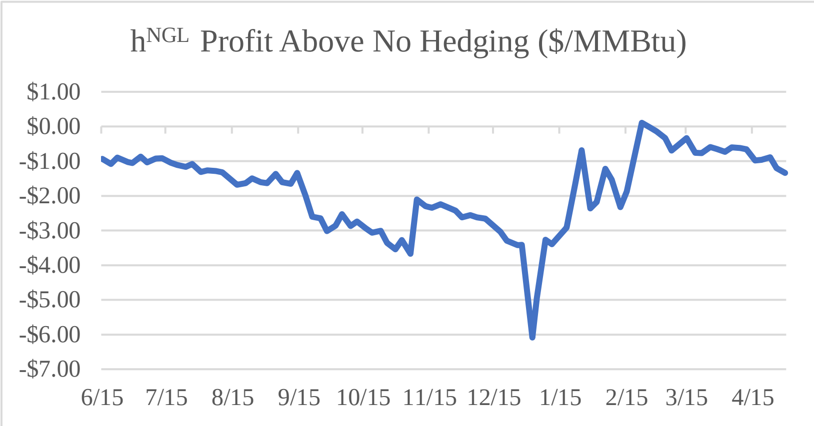



Exhibit 5: NGL Hedging Profit Above the No Hedging Strategy




Using bin widths of $0.10 in calculating the weighted Riemann sum leads to the creation of 29 unique bins. The $LPM_2$ of the naïve hedging strategy is 0.4401. 72 of the 87 observations resulted in a profit below the reference level.

**Power Hedging Strategy**

The average profit earned using the power hedging strategy is $4.74 per MMBtu. Exhibit 6 displays the profit earned by transformers that implement the power hedging strategy and Exhibit 7 displays the profit earned above or below a no hedging strategy.

Exhibit 6: Profit earned with the Power Hedging Strategy

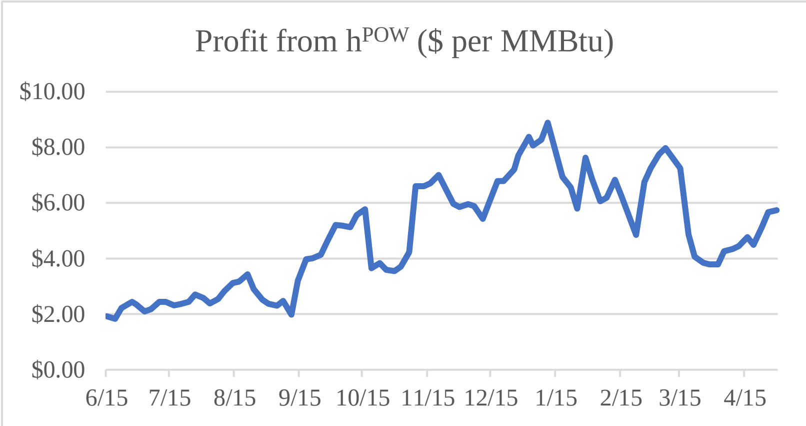
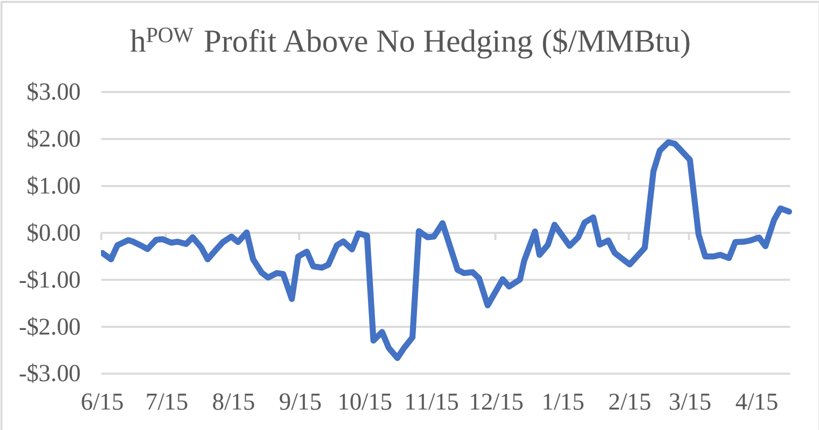



Exhibit 7: Profit Above or Below the No Hedging Strategy




Using bin widths of $0.10 in calculating the weighted Riemann sum leads to the creation of 29 unique bins. The $LPM_2$ of the power hedging strategy is 0.2638. 52 of the 87 observations resulted in a profit below the reference level. A comparison of the results is summarized in Exhibit 8.

Exhibit 8: Comparison of Hedging Strategies

| | No Hedge | Naïve Hedge | NGL Hedge | Power Hedge |
|---|---|---|---|---|
| **Average Profit** | $5.21 | $4.93 | $3.28 | $4.74 |
| **Max** | $8.38 | $9.05 | $5.48 | $8.89 |
| **Min** | $2.30 | $2.00 | $1.31 | $1.83 |
| **Standard Deviation** | 1.88 | 1.95 | 1.37 | 1.93 |
| **Observations Below $\bar{X}$** | 47.3% | 55.2% | 90.1% | 59.8% |
| **$LPM_2$** | 0.1757 | 0.2276 | 0.5622 | 0.2638 |

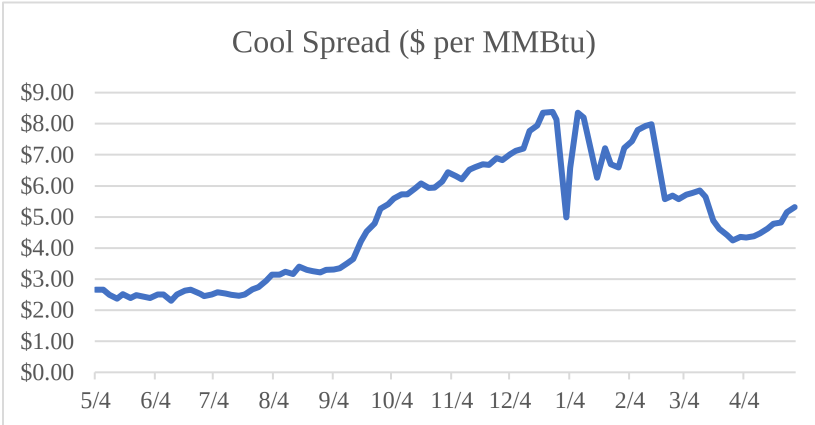
## DISCUSSION

The results show that transformers are better off if they do not implement any hedging strategy than they would be if they implemented any of the proposed strategies. These results are consistent with market conditions and this paper's use of $LPM_2$ as a measurement for hedging effectiveness, as discussed below.

### Analysis of Hedging Strategies

The relatively mediocre performance of the proposed hedging strategies can be explained in part by market conditions. Exhibit 9 plots the value of the cool spread during the period of observation, clearly showing its expansion in the past year.

Exhibit 9: Cool Spread Value in Observation Period




Given these market conditions, it is logical that transformers who did not insulate themselves from cool spread volatility would realize more profits than those who did as their operating margins increase alongside the cool spread. This is further compounded by the paper's use of $LPM_2$ as a proxy for hedging effectiveness as it only penalizes downside deviations. This was particularly severe in the fall of 2017, when the cool spread sustained an extended rally. Only when the cool spread began to contract in the spring of 2018 did hedging strategies begin to outperform the no hedging strategy.

The power hedge's $LPM_2$ statistic was comparable to naïve hedge, a result consistent with expectations. Given natural gas and electricity prices are highly correlated, the use of a power futures contract in a hedging bundle should not have produced results significantly different from a hedging bundle without it. However, in market conditions in which natural gas prices and electricity prices experience decoupling, this strategy could have use for transformers.

The NGL hedge's poor performance relative to the other hedging strategies is also expected given current market conditions. Ethane and propane prices are at historic lows, something that cannot be said about LNG. As a result, transformers who separate NGLs from wet gas would be creating an unfavorable product mix. By separating out ethane and propane, transformers would be reducing the quantity of LNG they can produce from the feedstock in order to produce the lower margin ethane and propane. While such a hedging strategy could be used for wet natural gas producers, obviously without the LNG component, it is not relevant for this paper. Transformers who use wet gas as a feedstock would elect to convert the entire quantity to LNG and thus this strategy does not reflect their economic realities.

**Limitations**

While this paper faces a number of limitations, none are so great as the availability of price data and the state of the LNG market. As discussed in the data section above, historical price data for a number of commodities and futures contracts critical to designing various hedging strategies is not publicly available or is updated infrequently. For example, global LNG spot prices are not publicly available, forcing this study to rely on the SLING index as a proxy for LNG spot prices. The same can be said for ICE's LNG futures contracts. Another issue inherit in the data is the frequency in which the prices of key commodities and futures are updated. Ethane, propane, and Louisiana MISO prices (spot and future) are often stale, reflecting the fact these commodities are infrequently traded. If the aforementioned commodities were traded in high volumes, in theory the hedging strategies this paper compares may effectively hedge the cool spread. However, in practice this is not the case.

Even if relevant price data was available for all the spot and futures prices of the commodities discussed, the hedging ratios and strategies would need to be adjusted substantially to reflect the position of each transformer. The variance in global LNG spot prices is much greater than in other comparable energy sources. For example, LNG exported to Japan from the U.S. in February 2018 was quoted at $7.46 per MMBtu while the equivalent price for export to Turkey was quoted at $4.34. While there is variance in other global energy benchmarks (i.e. WTI versus Brent for crude oil), such price discrepancies are not nearly as pronounced. Transformers would also need to adjust their hedging strategy to reflect the composition of their natural gas feedstock (wet or dry) to determine whether to hedge price fluctuations in NGLs.

Another limitation of this paper due to insufficient price data corresponds to the relative infancy of the ICE LNG futures contract. Because the ICE's LNG futures contract began trading in May of 2017, there are a limited number of possible data points. While NYMEX has listed an LNG futures contract since 2009, open interest and trading volume has been close to zero throughout its history. Only since ICE LNG futures officially begin trading did volumes pick up (ICE cleared 9,000 LNG contracts in January; NYMEX cleared 256), providing fresher price data. Because historical data is so limited it opens the data to idiosyncrasies that may have been avoided with more observations. Apart from some sharp contractions in the winter, the cool spread underwent dramatic expansion during the period of observation. Naturally in periods of cool spread expansion hedging will cut into transformers' profits and these strategized will be penalized in $LPM_2$ calculations.

Aside from limited price data on relevant commodities and their derivatives, there exists little data on LNG processing time. While there is an abundance of data regarding the refining timeline for crude oil, no such timeline exists for LNG, a figure critical for determining a hedging horizon. Similarly, transformers such as Cheniere do not disclose the quantity of natural gas feedstock they purchase nor, do they discuss relevant capacity constraints at their export terminals (Cheniere, 2018). Thus, this paper cannot make an accurate assumption regarding how long natural gas feedstock is stored at an export terminal before it undergoes liquefication. This is another critical consideration for determining the hedging horizon that is an unknown.

**Future Considerations**

Using the framework outlined in this paper, future research should consider the use of crude oil prices, spot and future, in designing new hedging strategies. Asian LNG spot prices are benchmarked to the crude oil, thus dependent on the price of oil. However, future studies will need access to more comprehensive data to determine an appropriate hedge ratio for a bundle of futures that includes crude oil. The data necessary, in addition to all relevant future and spot price, will be access to the methodology as to how Asian LNG futures prices are calculated using crude oil.

Another consideration will to use hedging ratios as outlined by Liu et al. (2016) when calculating the profit of each strategy. Instead of comparing strategies that utilize fixed hedging ratios, such as this paper does, researches should consider calculating the optimal hedge ratio defined as:

$$h^* = arg \min_{h} \int_{-\infty}^{\bar{\pi}} [\bar{\pi} - \pi(h)]^2 dF(\pi(h)) \tag{8}$$

Liu et al. (2016) find utilizing dynamic instead of fixed ratios increases hedging effectiveness in times of both high and low volatility in prices of the underlying commodity. This method is beyond the scope of this paper but an important consideration for future researchers.

## CONCLUSION

While the results of this paper show no benefit to transformers in implementing any of the proposed hedging strategies, the value can be found in the framework. If the forecasted growth of LNG materializes, more data regarding spot prices will become publicly available and LNG futures will trade in higher volumes. In addition, to more accurate pricing data, future studies will be able to take advantage of more data points that will give a more accurate picture of cool spread behavior. However, a number of uncertainties loom over LNG's future. The geopolitical situation in Russia, potential export regulations in the U.S., and a slow in the development of liquification technology are all situations that could have a profound impact on the LNG market in the near future. In summary, this paper does not answer the overarching question of how transformers can most efficiently hedge the cool spread. However, the paper's discussion of LNG market dynamics, hedging strategy design, and $LPM_2$ as a measure for efficient hedging may inform future studies of the cool spread.

# APPENDIX

## Appendix A: Natural Gas Liquids Hedge Ratio Calculations

Given:

- 28,814 billion cubic feet of wet natural gas production in the U.S. in 2017 (EIA, 2018)
- 2.61 million barrels of ethane and propane produced per day by gas plant production in 2017 (EIA, 2018)
- 0.0011 MMBtu per cubic foot of natural gas

$Annualized\ NGL\ Gas\ Plant\ Production = 952{,}650{,}000\ barrels$

$Wet\ Natural\ Gas\ per\ Barrel = 30{,}246.2\ ft^3$

$MMBtu\ per\ Gallon\ NGL =$
$1/(952{,}650{,}000\ barrels\ 30246.2\ ft^3 \times 0.0011\ MMBtu\ per\ ft^{3)} \times 42\ gallons = 1.26$

$Hedge\ Ratio\ per\ NGL = 1.26\ MMBTu\ per\ gallon\ \times 0.1\ part\ NGL\ per\ MMBtu\ NG = 0.13$

Thus:

$$\pi(h^{NGL}) = \frac{16}{20}S_1^{LNG} + \frac{3}{20}S_1^{ETH} + \frac{3}{20}S_1^{PRP} - S_0^{NG} + (F_1^{NG} - F_0^{NG}) + \frac{16}{20}(F_0^{LNG} - F_1^{LNG}) + \frac{3}{20}(F_0^{ETH} - F_1^{LNG}) + \frac{3}{20}(F_0^{PRP} - F_1^{PRP})$$

Assumption:

- Only ethane and propane production are considered given these two NGLs make up the vast majority of total NGL production (DOE, 2017)
- Wet natural gas composition ≈ 80% methane, 20% NGLs (NAESB, 2003)
- Ethane and propane are produced in equal parts, when in reality ethane makes up 54% of total ethane and propane production (DOE, 2017)

**Appendix B: Hedging Horizon Calendar**

| Prompt Month | Trading Abbreviation | Start Date | End Date |
|---|---|---|---|
| July 2017 | **N7** | **May 4, 2017** | **June 2, 2017** |
| August 2017 | **Q7** | **June 5, 2017** | **July 3, 2017** |
| September 2017 | **U7** | **July 5, 2017** | **August 3, 2017** |
| October 2017 | **V7** | **August 4, 2017** | **September 1, 2017** |
| November 2017 | **X7** | **September 4, 2017** | **October 3, 2017** |
| December 2017 | **Z7** | **October 4, 2017** | **November 1, 2017** |
| January 2018 | **F8** | **November 2, 2017** | **November 30, 2017** |
| February 2018 | **G8** | **December 1, 2017** | **January 3, 2018** |
| March 2018 | **H8** | **January 4, 2018** | **January 31, 2018** |
| April 2018 | **J8** | **February 1, 2017** | **March 2, 2018** |
| May 2018 | **K8** | **March 5, 2017** | **April 2, 2018** |
| June 2018 | **M8** | **April 3, 2017** | **May 2, 2018** |

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