Review of Literature

2.1 Database, Journals and Reports

To understand the various research and work done in this area of LNG business and volatility, the literature review was done from diverse sources like research articles, reports and manuscripts. The keywords used for searching in various journal databases are,

S.no	Keywords
1.	Liquefied Natural Gas (LNG)
2	LNG Markets
3	LNG Trade
4	LNG shipping
5	LNG Business
6	LNG India
7	LNG Volatility
8	GARCH
9	EGARCH
10	Energy Prices Volatility
11	Freight Volatility
12	Ship building prices
13	Time Charter rates

Table 2.1 keywords used for searching various journals and books

Using above keywords, the following were some of the prominent journals which were found to have research articles related to my topic of interest

S no	Name of the Journal	Database
1	Agrecon	
2	Applied Economics	Taylor and Francis
3	Applied Economics Letters	Taylor and Francis
4	Applied Financial Economics	Taylor and Francis
5	Automation in Construction	Elsevier
6	Cogent Economics and Finance	Taylor and Francis
7	Communications in Statistics-Simulation and Computation	Taylor and Francis
8	Economic Modelling	Elsevier
9	Energy	Elsevier
10	Energy Economics	Elsevier
11	Energy Policy	Elsevier
12	International Journal of Forecasting	Elsevier
13	International Review of Financial Analysis	Elsevier

14	Journal of Banking and Finance	Elsevier
15	Journal of Business and Economic Statistics	Taylor and Francis
16	Journal of Econometrics	Elsevier
17	Journal of information and optimization sciences	Taylor and Francis
18	Journal of International Money and Finance	Elsevier
19	Journal of Statistical Computation and Simulation	Taylor and Francis
20	Journal of Traffic and Transportation Engineering	Elsevier
21	Kybernetes	Emerald
22	Maritime Economics and Logistics	Palgrave
23	Maritime Policy and Management	Taylor and Francis
24	Procedia Social and Behavioural Sciences	Elsevier
25	Quantitative Finance	Taylor and Francis
26	Transportation Research Part E	Elsevier

Table. 2.2 List of some of the prominent journals

Apart from above journals, various reports related to the subject were collected and were reviewed. Some of them are listed below in table 2.3

S.no.	Name of the Report	Publisher
1	The LNG Industry 2006 to 2016 edition	International Group of Liquefied Natural Gas Importers
2	The British Statistical Review of World Energy, 2015	British Petroleum
3	The Asian Quest for LNG in Globalising Market	International Energy Agency
4	Wholesale Gas Price Survey -2014 edition	International Gas Union
5	World LNG Report -2013, 2014, 2015, 2016 editions	International Gas Union
6	Developing a Natural Gas Trading Hub in Asia	International Energy Agency

Table 2.3 List of some prominent reports related to LNG

2.2. Objectives of Literature Review

The three main objectives of Literature review are

1. To understand the natural gas markets and trade patterns and characteristics.
2. To study various volatility models applied in energy, natural markets and shipping freight markets.
3. To expedite the best fit models to study the volatility in LNG business.

2.3 Natural Gas Trade and Markets

The global LNG trade have been explained in (Maxwell & Zhu, 2011), (Kumar, Kwon, Choi, Hyun Cho, et al., 2011) and (Wood, 2012). Keeping in view the restrictions on CO_2, high emissions from Coal, some obstacles from renewable sources of energy, limitations on pipeline supply of natural-gas due to political and technical reasons and phasing out of nuclear power have been major factors behind growth and demand for LNG. The natural-gas prices fluctuations are likely to be commercial as domestic consumption is seasonal, dependent on temperature and inelasticity. Therefore, flexibility in supply of gas is essential for efficient operation of gas industry. The dramatic reduction in cost of LNG tanker ships and LNG liquefaction trains has made LNG more viable with long-term supply contracts coming into play. Lower tanker prices reduce capital costs, which reduce daily charter rates and as well cost of shipping. Thus, LNG imports or trade inversely proportional to LNG tanker prices.

Some study also has been done by to understand the role of LNG in increasing competitiveness in a natural-gas market by (Dorigoni, Graziano, & Pontoni, 2010). The empirical study was done in following conditions.

a. Bilateral oligopoly in LNG market.
b. Bilateral oligopoly with active spot market.
c. Competition between gas imported via pipelines and LNG.

The studies concluded that despite high LNG prices, the entry of LNG importers would have positive competitive effect if an active spot LNG market is developed and LNG costs decrease.

The key drivers for demand of LNG in a global market have been discussed in (S. Kamalakannan, n.d.), (Kumar, Kwon, Choi, Lim, et al., 2011) and (James T. Jensen, 2004) which were found to be.

a. Economic growth and energy demand.
b. Environmental concerns where natural gas being cleaner than other fossil fuels
c. Wider application of natural gas as a fuel source.
d. Deregulation of natural-gas market in key markets.
e. Improved technology and efficiency, which have contributed to reduction of liquefaction and regasification costs.
f. Insufficient domestic production and supply.
g. Escalating oil price.
h. Recovery of coal-bed methane.
i. Availability of natural gas from bio gas resource
j. The stranded gas phenomenon where companies are now willing to concentrate on gas discoveries and findings during exploration.

LNG also has been identified as clean affordable energy for Asia with limitations on pipelines in paper (Williams, Grant, & King, 1998) and (Rahul Tongia, 1999). Vector autoregressive model (VAR) has been developed for German natural-gas market to analyse the determinants of natural-gas price (Nick & Thoenes, 2014). From the analysis, it was found that natural-gas prices are affected by storage, temperature and shortfalls in supply in the short-term and in the long term the prices are affected by coal and crude oil prices.

The issues related to Globalisation of LNG markets were also discussed in (Sakmar & Kendall, 2009) and (Daniel Huppmann Ruester, Hirschhausen, & Gabriel, 2009) where they state that LNG industry is resilient to domestic disturbances and compensated when disruptions from other sources occur. Three distinct Natural-Gas trading regions were identified as namely.

a. Atlantic basin/North American
b. European Region
c. Asia-Pacific region

However, safety concerns of LNG were also identified such as terrorist threats, pool fires, flame less explosion and formation of flammable vapor clouds. World Gas model has been used to understand the different structural and regional gas market scenario.

Complex Network theory was also used to study the characteristics of Natural gas trade patterns in (Geng, Ji, & Fan, 2014) and following conclusions were drawn.

a. Pipeline gas and LNG have shown characteristics of scale-free networks. National heterogeneity appeared where minor exporting countries had most of the natural-gas resources and importing countries preferred those countries were already established trade relationships existed, which is a preferential feature of scale-free network.
b. The link between LNG trading countries was relatively close as LNG trade network had been having lower clustering coefficient and higher density as compared to pipeline gas network.
c. The Natural-gas markets between Asian, American and Europe were not integrated as single unified global natural-gas market. The Asian and European markets were more integrated and whole of North America was integrated within due to similarity in pricing mechanisms.
d. LNG would contribute to integration of fragmented natural-gas markets and development of inter-regional gas trade.

Gravity model also has been used to understand linking of natural-gas markets in (Barnes & Bosworth, 2015). The findings were that there is no relationship between levels of LNG trade and distance between two countries. The natural-gas trade is becoming less regional as LNG is linking these markets. Results also suggest that LNG trade has been increasing exponentially over past 20 years. The national income of both importing and exporting countries had a little effect on trading volumes of natural gas.

Among various regions of trade, the Asia pacific gas trade is dependent on LNG trade, and Asia dominates the world LNG trade market. Japan, Korea and Taiwan traditionally being leading importers, China and India have joined to import LNG. Since China and India had been large agricultural based economy, fertilizer industry would be a key driver for demand of natural gas.

In USA, the demand for Gas is driven by seasonal and long-term trends in production and consumption. Since consumption is seasonal and production is not seasonal, LNG was used during short term demand, which is seasonal. With discovery of Shale gas, USA can meet its domestic needs and is now turning out to be a net exporter from an importer.

The specific structures of LNG pricing in various regions have been detailed in (Che & Kompas, 2014). The pricing mechanisms in Asia-pacific region have been,

a. Oil Price Escalation Mechanism (OPE): The gas price is linked with competing fuels like gas oil, crude oil or fuel oils, with an escalation clause and a base price. Electricity and coal prices are also used in this OPE formulation for LNG.
b. Gas-on-Gas mechanism (GoG): Here the gas price determined by demand supply in the open market. The gas is sold and purchased for short term fixed prices and with long-term contracts. This pricing formula regulated prices at gas hubs like National balancing point in the United Kingdom and Henry hub at in the United States. Spot prices are also derived from this category.
c. Bilateral Monopoly (BIM): The pricing is determined between a large seller and large buyer through bilateral discussions and negotiations.

In the Asia-Pacific region, the price formula LNG contract is linked or indexed to the price of a basket of Crude oil imported to Japan, which is nick named as Japanese crude cocktail or Japanese custom cleared price (JCC). However, this mechanism has been challenged with crude oil prices touching more than US $ 100/barrel in the year 2008. Fukushima accident in March 2011 led to greater rise in demand for natural gas for electricity generation, which had enhanced LNG prices to be all-time high. This gave rise to disparity in LNG prices in Asia-pacific region and the market prices in North America. This gave rise to alternative pricing mechanism as the LNG importing nations had been under pressure due to high prices.

As discussed LNG prices are determined by JCC price as a reference benchmark in Asia-Pacific region. The LNG prices are calculated by oil prices based on energy equivalent basis of a barrel of oil energy.

$$P_{LNG} = \propto P_{JCC} \qquad \text{Equation (2.1)}$$

where

P_{LNG} is the LNG price

P_{JCC} is the JCC price,

α is the price slope reflecting an equivalent between LNG and crude oil. This slope ranges from 12.5% to 15.5% of the JCC oil price and it is constant sometimes.

According to (Davoust, 2008), the equation (1) has included a base price which is constant. Hence in some projects the relationship between JCC and LNG prices is given.

$$P_{LNG} = \delta + P_{JCC} \qquad \text{Equation (2.2)}$$

where

P_{LNG} is the LNG price,

P_{JCC} is the price of Japanese crude cocktail,

δ is the base value of LNG prices and

α is the price of slope of LNG to JCC prices.

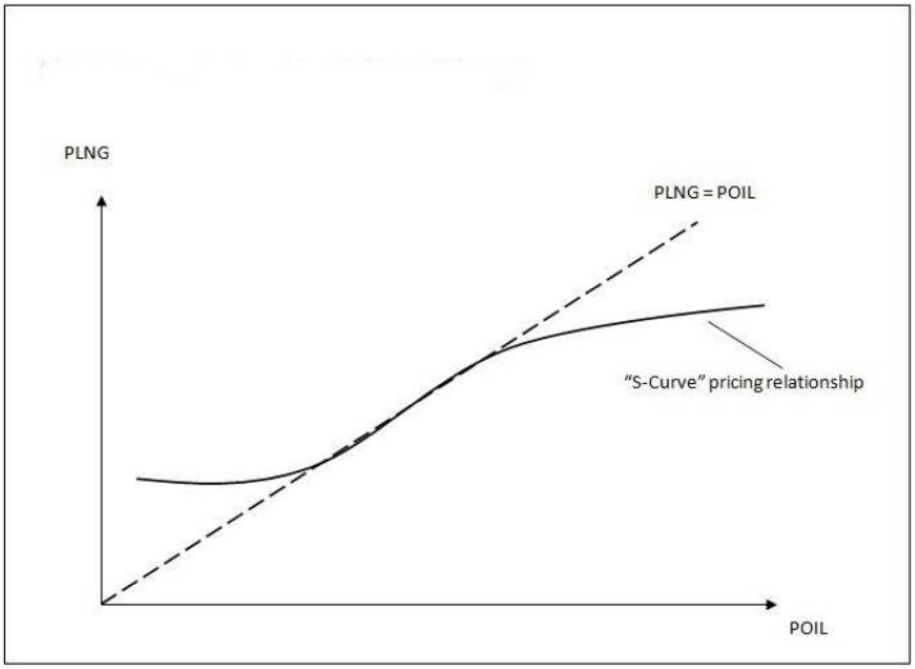

Figure 2.1 An illustration of the "S- Curve" Concept

Source: (Hartley, Kenneth B Medlock III, & Rosthal, 2006)

The S-curve formula as illustrated in figure 2.1, shows that decline in oil prices during 1980s has evolved in many Asian LNG contracts. The S-curve formula shows a linear relationship between price of crude oil and price of LNG but it contains price ceilings and floor to moderate the extreme impact of crude oil prices on LNG prices as discussed in (Hartley et al., 2006).

For the Asia-Pacific region, the LNG pricing formula following S-curve characteristics is given by

$$P_i^{LNG} = \delta_i + \propto_i P_i^{JCC} \qquad \text{Equation (2.3)}$$

Where i=1-3 indicates different ranges of JCC price level on the S-curve, δ_i is the base value of LNG prices. This could change depending on different JCC prices range as described in figure 2.1

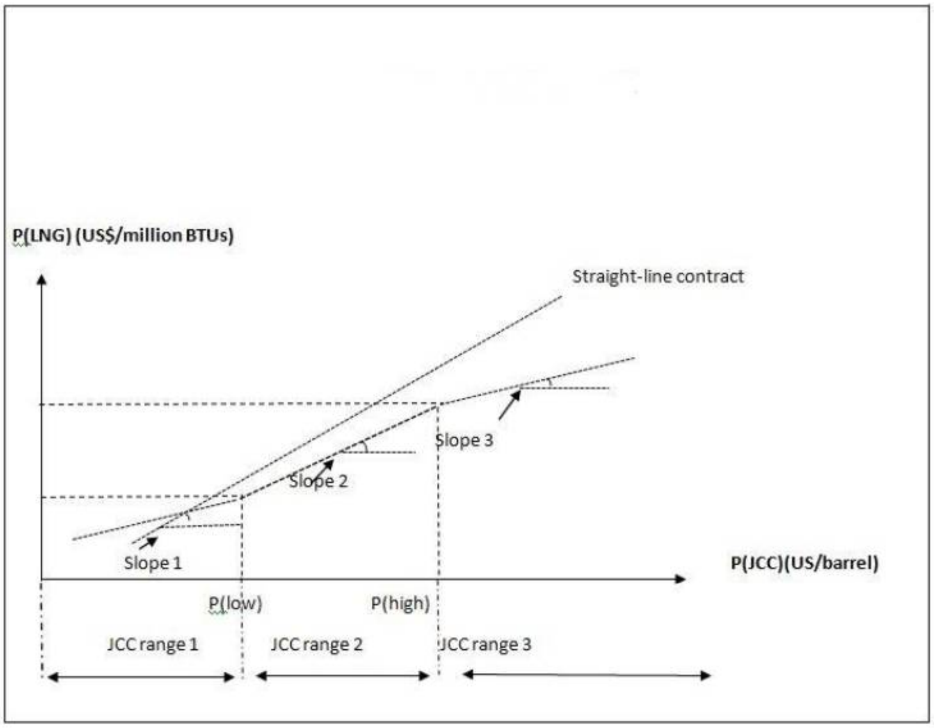

Figure 2.2 An illustration of different slopes in "S curve" for different JCC prices

Source: (Hartley et al., 2006)

With the rapid development of Shale gas in North America and disparity of LNG Henry Hub pricing could be better option for Asia-Pacific region. The Henry hub prices are historically less volatile and are at more stable levels. Elimination of risks linked to high oil prices which are affected by geopolitical, accident events and economic reasons can be done by this pricing. CIF cost of LNG from gulf coast in USA to Japan in US$/MMBtu can be calculated as

$$C_{HH}^{CIF} = P_{HH} + C_{LQ} + C_E + C_{CA} + C_S + C_R + C_{other} \quad \text{Equation (2.4)}$$

Where P_{HH} is the Henry Hub price,

C_{LQ} is cost of liquefaction

C_E is the cost of energy losses,

C_{CA} is the cost for capacity charge,

C_S is the cost of shipping,

C_R is the cost of regasification and

C_{other} is the other costs.

The emergence of Spot market with gas-on-gas pricing was also discussed in (Che & Kompas, 2014). The sudden rise in LNG demand post Fukushima accident, saw share of spot LNG grow from 16% in 2006 to 20% in the year 2013. Japan's spot price imports accounts for 48% of total spot LNG which was priced based on the Platt's JKM (Japan Korea and Marker) index. This is based on market conditions of demand and supply. The advantages are prices are versatile and low, although there is a risk of long-term supply security.

Net market value of natural gas (NMV) was investigated in each Asian economy in the paper (Miyamoto & Ishiguro, 2009). The NMV had the highest growth due to rise in crude oil price, but the Indian energy policy needs to be considered as fertilizer industry gets priority in the allocation of domestically produced gas which low priced. It is evident from the study that over period, the use for natural gas is expected to increase and need for more appropriate pricing solution was emphasised, moving away from JCC and Henry Hub pricing.

The challenges faced by Asian countries due to JCC pricing have been analysed in (Rogers & Stern, 2014). From the paper, the major findings were,

a. Japan would depend on Spot LNG cargo to meet its requirement before restarting nuclear-power generation. Apart from its existing JCC contracts, the country needs to expedite additional volumes post year 2020.
b. South Korea should look for additional LNG beyond year 2017, where present supplies are medium and long term contracted. Sourcing options could be USA, Australia, Russia and East Africa.
c. By the year 2020, India could supplement its present JCC and Henry hub linked long-term contracts with Spot volumes.

Vlado Vivoda has made a study in regard to Asian gas markets in paper (Vivoda, 2014b), where there was evidence of weakening of relationship between oil and natural-gas prices. Japan and Asian Countries held that LNG prices should not be liked to Crude oil prices. Even though energy security has been major reason for Japan to index with oil, but Japan has significantly increased shot-term and spot LNG purchases. Vlado Vivoda also has discussed about diversification of LNG imports in Asia (Vivoda, 2014a). From the paper, it is evident that India, China, Japan and Taiwan are looking for LNG beyond Qatar, which was the main supplier. Keeping in view the high costs due to oil indexing, these major importers are looking at other options like spot LNG, USA, East African countries, pipeline imports from Iran and Turkmenistan.

The recent revisions in LNG pricing terms have been studied in (Agerton, 2014). The study reveals that Japanese contracts were more often revised than any other country. A few of these were regarding revisions in S-curve formulas and in some in stances, there were eliminations of S-Curve formula when LNG was found to be traded at relatively low price instead of crude oil indexing. Korean and Taiwanese contracts which are single did not undergo much change. Even though it appears that LNG prices may continue to be indexed with crude oil prices, but a relationship between prices could be more complex than traditional thumb rules.

The question of emergence of World natural gas market has been discussed by Romain Davoust in (Davoust, 2008). There is evidence that a world gas price with some correlations and regressions could emerge in the coming years. Liberalization of Natural-Gas pricing has been successful bring down prices in USA and Europe. This is despite Europe dependent extremely on imports of natural gas. However, Asia could see high-price levels due to long distances between producing countries which in turn lead to high transportation costs.

There is evidence of wide variation price and price differentials persistent over years since Fukushima accident as discussed by Robert A. Ritz in (Ritz, 2014). The paper discusses where LNG producers were behaving irrationally by failing to accept international price arbitrage. This was despite world gas markets being effectively connected by LNG shipping. Rough estimates suggest Qatar's market power, which is albeit at different levels for Europe and Japan. Incentives, market power and some other constraints seem to be major factors hindering international price arbitrage.

Contract selection and Contract structures in LNG business between producer and buyer have been analysed in (von Hirschhausen & Neumann, 2008), (Khalilpour & Karimi, 2012) and (Ruester, 2009). Price dynamics and uncertainty were found to be a major concern in the contracts. However, owing to high capital investments, contracts were imminent keeping fuel supply and energy security factors.

The demand for natural gas and challenges had been analysed by Manish Vaid in (Vaid, 2014). Natural Gas emerges as the cleanest fuel and LNG as the best mode owing to limitations on pipeline dependency with supplying nations in middle east. For the growth of natural-gas imports to India, limitations on pipeline connectivity with middle east due to geo-political reason was a major hindrance for country's growth and energy security (Singh, 2008), (Shukla & Dhar, 2009) and (Tongia, 2005). Understanding various from above discussions, a consolidated list of research articles related to LNG markets and prices is given below.

S. No.	Paper Title	Authors	Publication and year
1	Natural-gas prices, LNG Transport Costs, and the dynamics of LNG imports	Don Maxwell, Zhen Zhu	Energy Economics, 2010
2	LNG is linking regional natural-gas markets: Evidence from the gravity model	Ryan Barnes, Ryan Bosworth	Energy Economics, 2014
3	A dynamic analysis on the global natural-gas trade network	Jiang-Bo Geng,Qiang Ji,Ying Fan	Applied Energy, 2014
4	LNG: An eco-friendly cryogenic fuel for sustainable development	Satish Kumar,Hyouk-Tae Kwoon,Kwang-Ho Choi,Wonsub Lim,Jae Hyun Cho,Kyungjae Tak	Applied Energy, 2011
5	The Globalization of LNG markets: Historical context, Current trends and Prospects for the Future.	Susan L.Sakmar,Donald R.Kendall	Proceedings from 1st Annual Gas Processing Symposium, Elsevier, 2009
6	The World Gas Market in 2030-Development Scenarios using the World Gas Model	Daniel Huppman,Ruud Egging,Franziska Holz,Sophia Ruester,Christian von Hirschhausen,Steven A.Gabriel	Working paper, German Institute for economic Research
7	The Development of a Global LNG Market	James T.Jensen	The Oxford Institute for Energy Studies,2004

8	Drivers for Demand of Liquefied Natural Gas(LNG) in a growing Global Market	S. Kamalakannan, Dr.B. Madhavan	AMET International Journal of Management,2012
9	Can LNG increase competitiveness in the natural gas market?	Susanna Dorigoni, Clara Graziano, Federico Pontoni	Energy Policy,2010
10	A review and outlook for the global LNG trade	David A. Wood	Journal of Natural Gas Science and Engineering,2012
11	Status and future projections of LNG demand and supplies: a global perspective	Satish Kumar, Hyouk-Tae Kwoon, Kwang-Ho Choi, Jae Hyun Cho, Wonsub Lim, Il Moon	Energy Policy, 2011
12	Challenges to JCC Pricing in Asian LNG Markets	Howard V Rogers, Jonathan Stern	The Oxford Institute for Energy Studies,2004
13	Natural gas in Asia: Trade, markets and regional institutions	Vlado Vivodo	Energy Policy,2014
14	LNG import diversification in Asia	Vlado Vivodo	Energy Strategy Reviews,2013
15	The Structure and Dynamics of Liquefied Natural Gas pricing in Asia and the Pacific and implications for Australia	Nhu Che, Tom Kompas	Crawford School Research Paper,2014
16	A New Paradigm for Natural Gas pricing in Asia: A Perspective on Market Value	Akira Miyamoto, Chikako Ishiguro	Oxford Institute for Energy Studies,2009
17	Natural Gas imports by South Asia: Pipelines or Pipedreams?	Rahul Tongia, V.S. Arunachalam	Economic and Political Weekly,1999

18	LNG: Clean Affordable energy for Power and Town Gas in Asia	M.F. Williams, C.W. Grant, N. King	Energy Sources,2007
19	Gas Price Formation, Structure and Dynamics	Romain Davoust	The Institut Francais des Relations Internationales,2008
20	Contract selection under uncertainty: LNG buyers' perspective	Rajab Khalilpour, I.A Karimi	Proceedings of 11th International Symposium on Process Systems Engineering,2012
21	The Relationship between Crude Oil and Natural Gas Prices	Peter Hartley, Kenneth B. Medlock III, Jennifer Rosthal	Energy Forum, James A. Baker III Institute for Public Policy,2007
22	Natural Gas in North America: Markets and Security	Peter Hartley, Amy Myers, Kenneth B. Medlock III	Energy Forum, James A. Baker III Institute for Public Policy,2007
23	The Development of Chinese Gas pricing: Drivers, Challenges and Implications for Demand	Michael Chen	The Oxford Institute for Energy Studies,2014
24	Long-term Contracts and Asset Specificity Revisited: An Empirical Analysis of Producer-Importer Relations in the Natural Gas Industry	Christian von Hirschhausen, Anne Neumann	Review of Industrial Organization,2008
25	Global LNG Pricing Terms and Revisions: An Empirical Analysis	Mark Agerton	Centre for Energy Studies, James A. Baker III Institute for Public Policy,2014

26	Revisiting Natural Gas Imports for India	Rahul Tongia	Economic and Political Weekly,2005
27	Changing Contract Structures in the International Liquefied Natural gas market: A First Empirical Analysis	Sophia Ruester	Working Paper, German Institute for Economic Research,2009
28	Price discrimination and limits to arbitrage: An analysis of global LNG markets	Robert A. Ritz	Energy Economics,2014
29	Capital structure in LNG infrastructures and gas pipelines projects: Empirical evidences and methodological issues	Axel Pierru, Simon Roussanaly, Jerome Sabathier	Energy Policy,2013
30	Strategic Analysis of technology and capacity investments in the liquefied natural gas industry	Erkut Sonmez, Sunder Kekre, Alan Scheller-Wolf, Nicola, Secomandi	European Journal of operational Research,2012
31	World LNG Shipping: Dynamics in markets, ships and terminal projects	Siyuan Wang, Theo Notteboom	
32	The LNG Market: A game theoretic approach to competition in LNG shipping	Konstantinos G. Gkonis, Harilos N. Psaraftis	Maritime Economics and Logistics,2009
33	What drives natural gas prices? A structural VAR approach	Sebastian Nick, Stefan Thoenes	Energy economics, 2014
34	Are natural gas spot and futures predictable	Vinod Mishra, Russell Smyth	Economic Modelling, 2016

Table 2.4 List of various research articles related to LNG markets and prices

Source: Various Journal databases

2.4 Volatility

The term “volatile” is very much associated with stock markets, which are very much unstable. This was very much prominent in the 1990s with unpredictable capital inflows associated with fickle sentiment in the growing market segments. The term “volatile” could be applied to weather conditions like many countries GDP is associated with good monsoon. This could also be related to political climate where the Oil prices could fluctuate due to change in governance. In the field of economics, the volatility dates when the study of business cycles was started. However, the volatility began to develop in into an independent subject in macroeconomics over the last two decades and this has occupied a central position in today’s development economics. The prominence of volatility was brought by Valeri Ramey and Garey Ramey in paper (Ramey & Ramey, 1995) where it was brought forward that volatility exerts negative impact on growth on the long run.

The best and early definition of volatility can be derived from (Knight, 1921) which states as “Volatility is an allied to risk in that it provides a measure of the possible variation or movement in a particular economic variable or some function of that variable such as growth rate. This is generally measured based on observed realizations of a random variable over a period. The volatility is commonly measured by standard deviation, which is based history of economic variable. Volatility can be measured by two methods: it can be measured by standard deviation of total variability or standard deviation of pure risk, which can be derived from the residual from a forecasting equation for whole variability. The idea that volatility tends to form a cluster where there could be serial correlation in it and modelling this by using auto regressive conditional heteroskedasticity was one of the key contributions, which led to Nobel Prize in 2003 by Robert F. Engle.

2.4.1 Volatility in Energy prices

There have been many studies related to volatility in financial markets using various models. However, keeping in view the high volatility in energy prices, especially in Petroleum markets Perry Sadorsky has used different univariate and multivariate models to forecast daily volatility in petroleum future price returns (Sadorsky, 2006). The various models used for understanding volatility in petroleum futures are.

a. Random walk model
b. Historical mean model
c. Moving Average model
d. Exponential smoothing
e. Least squares linear regression model
f. Auto Regressive model
g. GARCH (1,1) model
h. GARCH (1,1) in mean model with variance
i. TGARCH (1,1) model
j. State space model
k. Vector auto regression model
l. Bivariate GARCH (BIGARCH) model

From above it is quite evident that GARCH models are more prominent and good to fit in modelling energy prices. Therefore, various ARCH and GARCH type processes used in modelling Energy Prices have been discussed in (Khindanova Irina, Zauresh Ata khanova, 2004). From the book, various GARCH models were discussed for world oil markets, natural gas markets and electricity markets. Based on several applications of ARCH and GARCH models they have been summarised as following

a. ARCH model: The general equation is given below for ARCH (p) process

   $\varepsilon_t = \upsilon_t \sigma_t$

   $\sigma_t^2 = \omega + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \varepsilon_{t-2}^2 + \cdots + \alpha_p \varepsilon_{t-p}^2$ Equation (2.5)

Where ε_t is the error term of the mean process, σ_t^2 is the conditional variance of ε_t, v_t ~ iid (0,1), ω>0, α_1>= 0 for i = 1,…,p.

b. GARCH (1,1) model

c. GARCH-M: This model is used to find the efficiency of energy future prices and test the hypothesis of unbiasedness which is given by following equation mentioned below

$$y_t = \beta x_t + \delta\sigma_t + \varepsilon_t \quad \text{Equation (2.6)}$$

Or

$$y_t = \beta x_t + \delta\sigma_t^2 + \varepsilon_t \ , \quad \text{Equation (2.7)}$$

$$\sigma_t^2 = \omega + \alpha_1\varepsilon_{t-1}^2 + \beta_1\sigma_{t-1}^2 \ , \quad \text{Equation (2.8)}$$

Where y_t is the conditional mean of returns, x_t is the exogenous variable, where ε_t is the error term, σ_t^2 is the conditional variance of returns.

d. Asymmetric GARCH: This model is used to study the direction of price shock and is given below

$$\sigma_t^2 = \omega + (\alpha + \gamma d_{t-1})\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \quad \text{Equation (2.9)}$$

Where d_t =1 if ε_t<0 and 0 otherwise and γ is the "leverage term".

e. EGARCH: The model is also used to test the presence of leverage effect which is also called as Exponential GARCH. The equation used is given below

$$\log(\sigma_t^2) = \omega + \sum_{j=1}^{q}\beta_j\log(\sigma_{t-j}^2) + \sum_{i=1}^{p}\alpha_i\left(\left|\frac{\epsilon_{t-i}}{\sigma_{t-i}}\right| - \mathrm{E}\left|\frac{\epsilon_{t-i}}{\sigma_{t-i}}\right|\right) +$$

$$\sum_{k=1}^{r}\gamma_k\frac{\epsilon_{t-k}}{\sigma_{t-k}} \quad \text{and} \quad \epsilon_t = \sigma_t\eta_t \quad \text{Equation (2.10)}$$

f. FIGARCH: The model which is also called as Fractionally integrated GARCH is used when conditional variance is fractionally integrated. The equation is as given below

$$\sigma_t^2 = \frac{\omega}{1-\beta_{jj}(L)} + \lambda(L)\varepsilon_t^2 \quad \text{Equation (2.11)}$$

Where $\lambda(L) = 1 - \{\left[\frac{\phi(L)(1-L)^d}{[1-\beta(L)]}\right]\}$

g. ARMA-GARCH: The model is used where the mean of energy returns to time-varying and depend on its past values and past values of error term. The equation is given below

$$y_t - \phi_1 y_{t-1} - \phi_2 y_{t-2} - \ldots - \phi_r y_{t-r} = \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \ldots + \theta_s \varepsilon_{t-s} \qquad \text{Equation (2.12)}$$

If r=0, model is a moving average (MA) process. If s=0, then the model is an autoregressive (AR) process.

We can also express the above statement as

$$\phi(L)(1-L)^d y_t = \Theta\,(L)\varepsilon_t \qquad \text{Equation (2.13)}$$

Where $\varepsilon_t | y_{t-1} \sim N(0, \sigma_t^2), \Theta(L)$

h. AR-GARCH: Here in this model the conditional mean of prices r_t is an AR process and the conditional variance σ_t^2 is GARCH (1,1) process and the equation is

$$r_t = \phi_1 r_{t-1} + \phi_2 r_{t-2} + \phi_3 r_{t-3} + \phi_4 r_{t-4} + \varepsilon_t^2,$$

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2 \,. \qquad \text{Equation (2.14)}$$

i. MA-GARCH: This is model is used when the growth rate of prices is a moving average (MA) process of order one or two and the series follow GARCH (1,1) model. The equation is given below as

$$X_t = \sum B_s X_{t-s} + \mu_t \,, \qquad \text{Equation (2.15)}$$

Where X_t = {growth rates of industrial production, prices of oil, coal, iron and steel, as well as conditional variances of the growth rates of resource prices estimated by GARCH Models}, B_s is a vector of parameters and μ_t is a vector of heteroskedastic disturbances.

j. ARFIMA- GARCH: This model as described allows mean process of the energy returns which are fractionally integrated. The model is given in form of equation mentioned below

$\phi(L)(1-L)^d y_t = \Theta(L)\varepsilon_t,$ Equation (2.16)

where

$\varepsilon_t|y_{t-1} \sim N(0, \sigma_t^2),$ Equation (2.17)

and $\beta(L)\sigma_t^2 = \lambda + \alpha(L)\varepsilon_t^2$ Equation (2.18)

Where y_t is the time series, $\phi(L)$ and $\Theta(L)$ are lag polynomial operators from the ARMA process. *α(L)* and *β(L)* are lag polynomial operators from the GARCH process. 4d4 is the fractional differencing operator. The process is mean reverting for *d*<1 and it is covariance stationary if *d*<0.5. if $0.5 \leq d < 1$, then the process is mean reverting but has infinite variance.

k. SWARCH: Switching ARCH model was made for modelling conditional Heteroskedasticity when the regimes governing the volatility process change during the time which is under consideration. The equation is given below

$\frac{\sigma_t^2}{g_{s_t}} = \omega + \sum_{i=1}^{2} \alpha_i \frac{\varepsilon_{t-i}^2}{g_{s_{t-1}}} + \xi \frac{\varepsilon_{t-i}^2}{g_{s_{t-1}}} d_t$ Equation (2.19)

Where d_t=1 if ε_{t-1} <0 and 0 otherwise, g_{s_t} is the switching parameter corresponding to the state or regime s_t=1,2 and $\varepsilon_t \sim N(0, \sigma_t^2)$. The model is based on two regimes and two lags in conditional variance process.

l. Stable GARCH: In this model the performance of GARCH is evaluated based on Paretian distributions of the error term. The equation for stable GARCH is given below

$\varepsilon_t = c_t u_t$

$c_t = \omega + \sum_{i=1}^{p} \alpha_i |\varepsilon_{t-i}| + \sum_{j=1}^{q} \beta_i c_{t-i}$ Equation (2.20)

Where u_t is a stable variate with $\alpha > 0$ and $c_t > 0$.

From the above (Khindanova Irina, Zauresh Ata khanova, 2004) there has been extensive literature in regard modelling conditional heteroscedasticity of energy prices. However, the majority have used GARCH models of lower order like GARCH (1,1) models. Many applications have favoured modified GARCH models especially asymmetric GARCH and EGARCH. Most of the studies have been related to crude oil price data and a very few are related to natural, gas, coal, electricity and gasoline prices.

Apart from above some more research articles have been studied and a few have been discussed below.

MGARCH modelling was used to understand the volatility in electricity spot markets (Worthington, Kay-Spratley, & Higgs, 2005). Presence of ARCH and GARCH effects were present in the markets.

Antoniou and Foster have used GARCH model to examine the effects of futures trading on the price volatility of Brent crude spot oil market(Antoniou & Foster, 1992). From the results, it was evident that volatile shocks have perpetual effect on prices. From the GARCH-M model it showed that nature of spot market volatility has altered after introduction of futures contracts.

GARCH models have been used to prove Samuelson hypothesis in oil markets where the volatilities in futures returns increases as contracts approach maturity. The study was done in (Adrangi, Chatrath, Dhanda, & Raffiee, 2001) for crude oil, heating oil and unleaded gasoline future prices..

Bivariate GARCH and VAR methodology has been employed by Bahram (Adrangi, Chatrath, Raffiee, & D. Ripple, 2001) to study price dynamics of L.A. diesel fuel and Alaska North slope crude oil. From the results, it was evident that there is presence of uni-directional casual relationship between the two. It was also found that when there is price spread the L.A. Diesel market was found to bear the burden of convergence.

Various GARCH models have been applied for understanding volatility in crude oil prices. The volatility of futures on crude oil traded in New York Mercantile Exchange was studied(Marzo & Zagaglia, 2010). GARCH (1,1), EGARCH and GJR models were applied for understanding the volatility. Univariate and Multivariate GARCH models were applied to understand volatility in prices of electricity, natural gas and crude oil (Efimova & Serletis, 2014). Multivariate and univariate model were found to yield similar results and more accurate results were produced by univariate models. The advantage of multivariate models was to find the interactions among the three energy commodities, their volatilities and understand significant spill over effects. GARCH (1,1) model has been used to study the risk in future and spot prices of West Texas Intermediate crude oil (Moosa & Al-Loughani, 1994). The results showed presence of time varying risk premium which could be adequately modelled by GARCH-M process. To study the importance of resource price uncertainty and resource price levels of Crude petroleum, Bituminous coal, non-ferrous metals and iron and steel commodities on economic growth , GARCH models have been applied in (Boyd & Caporale, 1996). It was found that economic output growth was significantly influenced by resource price uncertainty and resource price levels. EGARCH, GARCH and ARFIMA-GARCH models were used by Mazaheri to study the convenience yields in the petroleum market (Mazaheri, 1999). From the results, it was evident that there is persistence of daily convenience yields which provides market observations for expected future spot price. It was found that for unleaded gasoline and heating oil conform with the theory of storage and the convenience yield is more volatile for positive shocks.

A comparison between GARCH models and Markov switching was done in risk modelling of crude oil markets(Luo, Seco, Wang, & Wu, 2010). The findings suggest that GARCH models are more suitable where there is a unique stochastic process with conditional variance. However, Markov regime switching models were having advantage of dividing the observed stochastic behaviour in a time series into various separate phases.

The performance of multivariate and univariate GARCH models was studied by forecasting volatility in crude oil, conventional gasoline, heating oil and jet fuel spot prices (Wang & Wu, 2012). The results show presence of asymmetric effects and significant persistence. The performance results based on SPA test (Hansen, 2005) show that multivariate models perform better than univariate models. Therefore, it could be concluded that energy market participants should calculate individual volatilities of related prices and to obtain greater forecasting accuracy correlation should be considered.

Bivariate VARMA, GARCH-in-mean, asymmetric models have been used in (Rahman & Serletis, 2012) to investigate relationship between oil price uncertainty and GDP of Canada. From the empirical analysis, we find that uncertainty in oil price relates to low GDP growth rate of Canada. Similarly, Bivariate GARCH model was used to investigate persistent volatility spills from the crude oil price to inflation in Taiwan(Lu, Liu, & Tseng, 2010). The results from the model show that oil price volatility does predict inflation. However, volatility transmissions between inflation and oil price seem to be insignificant. There are also other models which were used to understand volatility transmission like in (Le Pen & Sévi, 2010) and (Wenming shi, Zhongzhi Yang, 2013) where Structural vector autoregressive model and volatility impulse response function method were applied to understand the volatility transmission.

There are few more studies regarding successful application of GARCH models in natural gas markets. In the paper (Lv & Shan, 2013) forecasting of price volatility was done for spot and future prices of natural gas prices in USA. Linear and non-linear GARCH models were applied and based on SPA test it was found that none of the models were superior to each other in forecasting accuracy. Simple linear GARCH models were better in forecasting spot price volatility. Non-linear models were superior in forecasting future price volatility. Therefore, Linear GARCH models are better for risk management and for speculators bot linear and non-linear models could be considered. Similarly GARCH model was also applied to study the relationship between supply-demand and natural gas market in

UK(van Goor & Scholtens, 2014). The results from EGARCH and M GARCH models confirm presence of leverage effect. The impact of weather shocks and storage on natural gas prices volatility in US markets was studied using GARCH model(Mu, 2007). From the empirical analysis using GARCH it was evident that weather shock and storage reduce volatility persistence by 40%. Volatility transmission in the natural gas and oil markets was studied using GARCH model with BEKK parameterization(Ewing, Malik, & Ozfidan, 2002). From the empirical results, it is evident that volatility persistence is there in both the markets and volatility in natural gas returns is more persistent than in oil returns. Vinod Mishra has tried to answer couple of questions whether natural gas future prices predict natural gas spot prices and whether they can predicted using historical data (V. Mishra & Smyth, 2016). For the first question, it was found that natural gas futures do not predict the magnitude of futures prices and the answer to second question was that if unit root test was applied to historical data, then natural gas spot prices and future prices were found to be predictable. A study has also been done to understand whether events in natural gas prices cause effects on crude oil market (Halova Wolfe & Rosenman, 2014).

EGARCH model has been used to study the volatility and the results indicated presence of relationship between the two markets. Univariate GARCH models and multi variate models VARMA, GARCH-in-mean and BEKK models have been used to study the price behaviour in Oil, natural gas and Coal markets (Serletis & Xu, 2016). A trivariate BEKK model was used to study the interdependence of natural gas, oil and coal volatilities and returns. GARCH models have also been used to study the daily volatility of natural gas nearby- month futures traded on NYMEX (Ergen & Rizvanoghlu, 2016). The results indicated that high volatility existed with seasonal temperatures and divergent storage levels. There was evidence of asymmetric impact of storage levels on volatility. Presence of asymmetric effect due to weather shocks was also evident. GARCH (1,1), EGARCH and ARMA models have been used to study relationship between energy commodity prices and price volatilities in U.S.A. (A. K. Mishra, 2013). The static and dynamic long-run and short-run interaction between the prices of natural gas, crude oil, heating oil and propane was studied. From the above study, GARCH (1,1), EGARCH and Asymmetric GARCH are the most commonly fit models in modelling energy prices. A consolidated list of research articles has been listed below mentioning the theme and research gap.

S no.	Paper Title	Authors	Publication and year	Theme	Research Gap
1	Energy Markets Volatility Modelling using GARCH	Olga Efimova, Apostolos Serletis	Energy Economics, 2014	Univariate and multivariate GARCH modelling of Oil, natural gas and electricity prices in USA market. Estimation BEKK and DCC models	No empirical GARCH analysis between Henry Hub prices and JCC prices
2	Modelling Natural Gas market volatility using GARCH with different distributions	Xiaodong Lv, Xian Shan	Physica A, 2013	GARCH-class modelling of natural gas spot and future prices in USA. Accuracy of forecasting was better for GARCH- class models with asymmetric affects.	No empirical GARCH analysis between Henry Hub prices and JCC prices
3	Risk Modelling in Crude oil market: a comparison of Markov	Cuicui Luo, Luis A. Seco, Haofei Wang, Desheng Dash Wu	Kybernetes, 2010	GARCH modelling of NYMEX crude market prices were done and it was found useful for modelling stochastic process	No Volatility analysis done between JCC and Henry Hub prices

	switching and GARCH models				
4	Modelling of Natural Gas price volatility: The case of the UK gas market	Harm Van Goor, Bert Scholtens	Energy, 2014	Volatility of British Gas prices using Kanamura supply and demand model. Presence of leverage effects in GARCH models	No Volatility check of JCC and Henry Hub prices
5	Volatility transmissions between shocks to the oil price and inflation: evidence from a bivariate GARCH approach	Wen-Cheng Lu, TING-Kun Liu, Chia-Yu Tseng	Journal of Information and Optimization Sciences, 2010	Study of volatility between Oil prices and inflation in USA, Japan and Europe which establishes link between the two.	The study could be done volatility transmissions between natural gas or LNG and other factors like inflation

6	Modelling and forecasting petroleum futures volatility	Perry Sadorsky	Energy Economics, 2006	Univariate and multivariate statistical models used for petroleum futures volatility, TGARCH and GARCH models were found suitable in some cases, Values at risks were also calculated for Brent crude oil, heating oil and natural gas.	Volatility check for JCC prices and Henry Hub index prices could be done
7	Volatility transmission in the Oil and natural gas markets	Bradley T. Ewing, Farooq Malik, Ozkan Ozfidan	Energy Economics, 2002	GARCH modelling of Oil index prices and gas index prices from 1996 to 1999 was done.	Henry Hub and JCC prices GARCH modelling was not done
8	Transmission of prices and price volatility in Australian electricity spot	Andrew Worthington, Adam Kay-Spratley, Helen Higgs	Energy Economics, 2005	Volatility of five regional electricity markets in Australian National Electricity Market was done using multivariate GARCH	Henry Hub and JCC prices GARCH modelling was not done

	markets: a multivariate GARCH analysis				
9	Weather, Storage, and natural gas price dynamics: fundamentals and volatility	Xiaoyi MU	Energy Economics, 2007	study of volatility of natural gas futures prices are impacted by weather conditions in USA and storage. Samuelson effect was also studied. GARCH modelling used.	Henry Hub and JCC prices GARCH modelling was not done
10	Oil price uncertainty and the Canadian Economy: Evidence from a VARMA, GARCH-in-	Sajjadur Rahman, Apostolos Serletis	Energy Economics,2012	Bivariate VARMA, GARCH-in-Mean and asymmetric BEKK model used to study relationship between economic activity and oil price uncertainty in Canada	VARMA, GARCH-in-Mean and BEKK model for Henry Hub and JCC prices

	Mean, symmetric BEKK model				
11	Volatility transmission and volatility impulse response functions in crude oil markets	Xiaoye Jin, Sharon Xiaowen lin, Muchael Tamvakis	Energy Economics, 2012	VAR-BEKK model used to find crude oil markets volatility for prices at WTI, Dubai and Brent futures. Volatility impulse response functions analysis was done for 2008 financial crises and BP deep water oil spill.	for JCC index and Henry Hub prices VIRF analysis was not could be explored
12	Forecasting energy market volatility using GARCH models: Can multivariate models beat univariate models?	Yudong Wang, Chongfeng Wu	Energy Economics, 2012	Univariate and multivariate GARCH modelling done for volatility of conventional gasoline, jet fuel, crude oil prices in USA. Univariate models with asymmetric affect seem to display greater accuracy.	Univariate and multivariate modelling not done for Henry Hub and JCC prices.

13	Volatility forecasting for crude oil futures	Massimiliano Marzo, Paolo Zagaglia	Applied Economics Letters, 2010	GARCH modelling used for future prices of crude oil traded in Newyork Mercantile Exchange. E-GARCH and GARCH-G model fare best for forecasting.	GARCH modelling of Henry Hub prices and JCC prices could be done
14	Is monthly US natural gas consumption stationary? New evidence from a GARCH unit root test with structural breaks	Vinod Mishra, Russell Smyth	Energy Policy, 2014	GARCH Unit root tests were applied on monthly natural gas consumption in USA to find if data is stationary and its implications on policies which effect the natural gas consumption in energy mix of USA	Similar roots tests could be applied Natural Gas Index prices to find the if the data is stationary.
15	Asymmetric Impacts of Fundamentals on the Natural Gas Futures	Ibrahim Ergen, Islam Rizvanoghlu	Energy Economics, 2016	GARCH methods used to study volatility in natural gas futures and crude oil storage report	Similar study could be done for Henry Hub and JCC prices

	Volatility: An Augmented GARCH approach				
16	Bidirectional Causality in Oil and Gas markets	Robert Rosenman, Marketa Halova Wolfe	Energy Economics, 2014	EGARCH model used to volatility between oil inventory surprise and gas inventory surprise data published by EIA	EGARCH could be used to study volatility between JCC and Henry Hub prices
17	Is there any crucial relationship amongst energy commodity prices and price volatilities in the U.S.?	Alok Mishra	International Journal of Quantitative and Qualitative Research Method, 2013	GARCH and EGARCH models used to study the static and dynamic long-run and short run volatility between crude oil, natural gas, heating oil and propane in USA.	EGARCH and GARCH models could be used to understand volatility between various LNG Index prices

18	Volatility and a century of energy markets dynamics	Apostolos Serletis, Libo Xu	Energy Economics, 2016	Univariate and multivariate GARCH models used to understand volatility in oil, natural gas and coal volatilities.	Similar study could be done to understand volatility between various natural gas index prices
19	Alaska North Slope crude oil price and the behaviour of diesel prices in California	Bahram Adrangi, Arjun Chatrath, Kambiz Raffiee, Ronald D. Ripple	Energy Economics, 2001	VAR and bivariate GARCH models used to understand relationship between price dynamics of L.A. diesel fuel prices and Alaska North slope crude oil.	The relationship between various natural gas index prices could also be investigated using bivariate GARCH and VAR methodology
20	Chaos in oil prices? Evidence from futures markets	Bahram Adrangi, Arjun Chatrath, Kanwalroop	Energy Economics,2001	GARCH, EGARCH and AGARCH models used to study volatility in crude oil, unleaded gas and heating oil markets	Similar models could be used to study in Henry Hub and JCC

		Kathy Dhanda, Kambiz Raffiee			index prices of Natural Gas
21	Convenience yield, mean reverting prices, and long memory in the petroleum market	A. Mazaheri	Applied Financial Economics, 2010	ARFIMA-GARCH methodology used for understand volatility and behaviour of energy convenience yields in crude oil, unleaded gasoline and heating oil markets	similar methodology could be used in international natural gas price indexes
22	Resource Price uncertainty, and Economics Growth	Roy Boyd, Tony Caporale	Land Economics, 1996	ARCH and GARCH methods used to study volatility in price indexes for Crude Petroleum, Bituminous coal, iron and steel, non-ferrous metals and overall price producer index	Similar models could be used to study in Henry Hub and JCC index prices of Natural Gas

23	Unbiasedness and time varying risk premia in the crude oil futures market	Imad A. Moosa, Nabeel E. Al-Loughani	Energy Economics, 1994	GARCH model used to study the time varying risk in future and spot prices of West Texas Intermediate crude oil prices	GARCH model could also be used for understanding time varying risk in Natural Gas Index prices
24	Volatility, Storage and Convenience: Evidence from natural gas markets	Raul Susmel, Andrew Thompson	The journal of Future Markets, 1997	GARCH, SWARCH models have been used to investigate volatility in natural gas prices purchased by electricity utility markets from 1974 to 1994 in USA	Similar models could be used to analyse volatility in JCC and Henry Hub Index prices
25	The effect of futures trading on spot price volatility: evidence for	Antonios Antoniou and Andrew J. Foster	Journal of Business Finance and Accounting, 1992	GARCH model has been used to investigate the effects of futures contract of Brent crude oil on the volatility of spot market of Brent crude oil	GARCH model could be used for similar studies in Henry Hub and JCC prices

	Brent crude oil using GARCH				
26	The Relationship between Crude Oil and Natural Gas Prices	Peter Hartley, Kenneth B. Medlock III, Jennifer Rosthal	Energy Forum, James A. Baker III Institute for Public Policy,2007	Vector error correction model used to study the relationship between crude oil and natural gas prices	VECM model could be used to study relationship between JCC and Henry Hub prices of natural Gas

Table 2.5 List of research articles related to volatility in energy prices

Source: Various Journal Databases

2.4.2 Volatility in Shipping Freight markets

To study the volatility in the shipping markets sector, the present literature review could be segregated in two sectors namely Dry bulk markets and Tanker markets

2.4.2.1 Dry Bulk markets

GARCH(1,1) model was used to analyse volatility persistence in Baltic Capesize Freight Index in (Fan, Xing, & Yang, 2014). The results indicated that actual values and predicted ones are fitted and GARCH model was found to be suitable. Various univariate and Multivariate models were used to forecast spot prices of freights in various categories of bulk carriers and tankers. ARMA, GARCH, E-GARCH, VAR and VECM models were used to forecast spot market freights. VAR model was found to give best results compared to other univariate models. E-GARCH model was found to give best results compared to other multivariate models. GARCH-BEKK model has been applied to know the transmission in freight volatility between China container freight Index and Baltic Dry index (Hsiao, Chou, & Wu, 2013). The model brought forward the lead-lag relationships between Baltic Dry Index of bulk freights and China Container Freight Index. To understand the relationship between time charter rates and spot charter rates in dry bulk shipping Vector error correction model has been applied (Zhang & Zeng, 2015). Capesize, Supramax and Panamax vessels data has been taken where the empirical studies show that there is two-way lead-lag relationship between spot and time charter rates. Nelson's EGARCH model has been used to find the leverage effect in international dry bulk shipping market (Chen & Wang, 2004). The daily return time series of Handymax, Panamax and Capesize vessels in four different sea routes has been examined the leverage effect or asymmetric volatility. EGARCH model was found to be ideal model which proved that there was existence of asymmetric impact between current volatility and past innovations. VAR models have been used to understand the asymmetric long-memory property of volatility in dry bulk freight rates(Chang, Chih Chou, & Chou Wu, 2014). It was also found that asymmetric IAPARCH model gives better results for various dry bulk freight rates. The effects of increase in fleet size on freight rate volatility are evident in research paper (Xu, Yip, & Marlow, 2011). AR- GARCH model was applied for measuring freight rate volatility. The relationship between fleet size growth and freight rate volatility was measured through GMM regression and studies disclose that there is positive affect of fleet size on freight rate volatility. The spot rate volatility of capsize vessels found to have greater reaction to change in fleet size.

Kavusssanos has used VECM GARCH to investigate volatilities between spot and future Forward Freight Agreements (Kavussanos & Visvikis, 2004). In other studies the same author has used GJR-GARCH model (Kavussanos, Visvikis, & Batchelor, 2004) to study the asymmetric impact of news on volatility of Forward Freight Agreements. Stochastic volatility model was also used in (Gong & Lu, 2013) to analyse the volatility in daily price of Panamax Forward Freight Agreements where evidence of volatility persistence could be seen. Non-linear methods also have been used for forecasting freight rates for dry bulk carrier (Goulielmos & Psifia, 2009). Interestingly, SARIMA and GARCH models have also been applied to understand volatility and accurate forecasting for grain freight rates of dry bulk carriers(Emrah Bulut, 2013). Some Dynamic spill overs were investigated by Dimitris (Tsouknidis, 2016) where a multivariate DCC-GARCH model has been employed for understanding in Dry-bulk and tanker markets. The study revealed the existence of prominent

Volatility spill over effects in the shipping freight markets which were intense in the period of global financial crisis. It was also evident from the study that smaller vessels transmitted volatility spill overs to bigger vessels in the same dry bulk segment.

2.4.2.2 Tanker Market

There are limited studies related to volatility in tanker markets. Kavusssanos used VaR models like Random walk, GARCH and Risk metrics for understanding medium term risk forecasting in tanker markets(Kavussanos & Dimitrakopoulos, 2011). GARCH-X and EGARCH models have been used to investigate the asymmetric effects between dry bulk and tanker freight markets (Drobetz, Richter, & Wambach, 2012). The empirical analysis show that presence of asymmetric effects in tanker market but absence of asymmetric effects in dry bulk market. Non-parametric Markov diffusion model has been used to understand the dynamics of freights rates in tanker markets(Adland & Cullinane, 2006).

Kavusssanos has used GARCH models to examine the dynamics conditional volatilities in second-hand dry bulk ship markets (Kavussanos, 1997). The volatilities in Handymax, Panamax and Capesize second hand prices were investigated. Kavusssanos has also used Cointegrating Error Correction ARCH models to study the relative risks involved in operating different sizes of tanker vessels and also owning them in time-charter and spot markets (Kavussanos, 2003). The author has used ECM-GARCH model to understand the volatility in tanker markets. From the above discussion, it is evident that GARCH (1,1), EGARCH and Asymmetric GARCH models are the more fit than others for modelling volatility in shipping freight markets. Similar models could be used for modelling LNG freight rates. A consolidated list of research articles has been listed below for reference.

S. No	Paper Title	Authors	Publication and year	Theme	Research Gap
1	Dynamics of time-varying volatility in the dry bulk and tanker freight markets	Wolfgang Drobetz, Tim Richter, Martin Wambach	Applied Economics,2012	GARCH-X, EGARCH, EGARCH-X models discussed for dry bulk and tanker freight markets from Baltic dry Indices.	No volatility study related to LNG freight rates
2	Value at risk analysis of the asymmetric long-memory volatility process of dry bulk freight rates	Chao-Chi Chang, Heng Chih Chou, Chun Chou Wu	Maritime Economics and Logistics, 2014	Value at Risk models are applied for Volatility analysis of dry bulk freights. FIGARCH, Hyperbolic GARCH, fractionally integrated APARCH models used to analyse performance of VaR models. Asymmetric FIAPARCH outperforms other models in this case	No study regarding LNG freight rates
3	Market interactions in returns and volatilities between spot and forward	Manolis G. Kavusssanos, Ilias D. Visvikis	Journal of Banking and Finance, 2004	VECM-GARCH modelling used for Lead-Lag relationship in both returns and volatilities between spot and future shipping freight markets	No study about LNG shipping future freight markets

	shipping freight markets				
4	Forecasting Sport prices in Bulk Shipping	N.D. Geomelos and E. Xideas	Cogent Economics and Finance, 2014	Multi variate Models like VECM and VAR, Univariate models like ARIMA, GARCH and EGARCH used for forecasting the spot prices in bulk shipping	There is no modelling regarding spot prices of LNG shipping has been used.
5	Market risk model selection and medium-term risk with limited data: Application to ocean tanker freight markets	Manolis G. Kavusssanos, Dimitris N. Dimitrakopoulo s	International Review of Financial Analysis, 2011	Volatility of Tanker freight markets using GARCH and Value at Risk models	There is no analysis for LNG shipping markets
6	The dynamics between freight volatility and fleet size growth in dry	Jane Jing Xu, Tsz Leung Yip, Peter B. Marlow	Transportation Research Part E, 2011	AR-GARCH model used for determining freight rate volatility. GMM regression used to find relationship between freight rate volatility and fleet size growth	Similar analysis could be done for LNG fleet and freight rates

	bulk shipping markets				
7	Study of relationship between the time charter and spot freight rates	Hong Zhang, Qingcheng Zeng	Applied Economics,2014	VECM model developed to find the influence of time charter rates on spot freight rates in dry bulk shipping.	Relationship between Time charter rates and spot rates of LNG shipping could be analysed
8	The dynamics of time-varying volatilities in different size second-hand ship prices of the dry-cargo sector	Manolis G. Kavusssanos	Applied Economics, 1997	ARCH models used to find the dynamic of conditional volatilities for second hand ships in the world dry bulk market	similar analysis for second hand/new ships for LNG shipping markets could be done
9	An analysis of Freight rate volatility in dry	Lu Jing, Peter B. Marlow and Wang Hui	Maritime Policy and Management, 2008	The volatility characteristics in dry bulk market consisting of panamax, Capesize and handy size have been examined using GARCH and	Similar characteristics could be examined in

	bulk shipping markets			EGARCH model was applied to investigate asymmetric characters.	LNG Shipping Markets
10	Forecasting weekly freight rates for one-year time charter 65000 bulk carriers, 1989-2008, using non-linear methods	Alexandros M. Goulielmos, Maria-Elpiniki Psifia	Maritime Policy and Management, 2010	Rescaled Range Analysis, Power spectrum Analysis, V-statistics and BDS statistic were used for forecasting and predicting one year time charter weekly freight rates	Analysis related to LNG charter rates need to be done
11	The empirical evidence of Leverage effect on volatility in international bulk shipping market	Yung-Shun Chen, Shiu-Tung Wang	Maritime Policy and Management, 2006	To find leverage effects EGARCH model has been used for volatility in international bulk shipping market	Leverage affect need to be investigated in LNG shipping markets
12	Prediction of Baltic Capesize Freight Index Based on GARCH model	Fan Yonghui, Xing Yuwei, Yang Hualong	Applied Mechanics and Materials, 2014	GARCH method used to forecast Baltic Capesize Index	LNG shipping rates forecasting need to be done using GARCH

13	Over-the-counter forward contracts and spot price volatility in shipping	Manolis G. Kavusssanos, Ilias D. Visvikis, Roy A. Batchelor	Transportation Research Part E, 2004	GJR GARCH model used to examine the impact of Forward Freight Agreement on spot market price volatility in dry bulk shipping industry.	Similar analysis could be done for LNG freight rates
14	Volatility of Forward price in dry shipping market	Xiaoxing Gong, Jing Lu	Procedia social behavioural sciences	Stochastic Volatility model used to find the volatility of Panamax forward freight agreement	stochastic volatility could be done for LNG shipping also
15	Am empirical analysis of freight rate and vessel price volatility transmission in global dry bulk shipping market	Lei Dai, Hao Hu, Di Zhang	Journal of Traffic and Transportation Engineering, 2015	BEKK GARCH model used to find the volatility transmission effect from the new building, second hand market and freight market in dry bulk shipping market	BEKK GARCH model could be used in new building, second hand market and freight markets in LNG Shipping

16	A comparative study on ARIMA and GARCH models in forecasting newbuilding prices in tanker market	Dr. Nikolas D. Geomelos	Symposia papers SYMP, 2012	GARCH, E-GARCH, ARIMA-GARCH models used to find volatility of freights in five different sizes of tanker ships.	similar models could be used for LNG shipping freights
17	Return lead-lag and volatility transmission in shipping freight markets	Yao-jen Hsiao, Heng-Chih Chou, Chun-Chou Wu	Maritime Policy and Management, 2013	Study of transmission between container shipping and dry bulk shipping freight markets done using BEKK GARCH model.	Similar study could be done for LNG shipping freight markets
18	A study of trip and time charter freight rate indices: 1968-2003	Alexandros M. Goulielmos, Maria-Elpiniki Psifia	Maritime Policy and Management,2007	Brock, Dechert and Scheinkman test has been applied to find if the freight rates indices were identical and independent	Similar test could also be applied on LNG shipping freight indices
19	Modelling forward freight rate dynamics-	Steen Koekebakker, Roar Os Adland	Maritime Policy and	Heath-Jarrow-Morton framework was used to study the volatility in Time charter rates of dry bulk carriers	Similar framework could be used in

	empirical evidence from time charter rates		Management,2004		LNG shipping time charter rates
20	Dynamic volatility spill overs across shipping freight markets	Dimitris A. Tsouknidis	Transportation Research Part E, 2016	Multi variate DCC-GARCH model used to study the volatility spill overs between tanker freights and dry bulk freights	Similar study could be done for LNG shipping freight markets
21	Time varying Risks among segments of the tanker freight markets	Manolis Kavusssanos	Maritime economics and Logistics, 2003	Co integrating error correction ARCH models used to study the risks involved in time charter and world spot charter rates in tanker markets	Similar study could be done for time charter rates of LNG shipping
22	Seasonal Fuzzy Integrated Logical Forecasting (SFILF) Model for te Grain Freight rates of Dry Carriers	Emrah Bulut,Shigeru Yoshida	IAME Conference,2013	SARIMA and GARCH (1,2) models were used to expedite volatility in time charter rates for grain shipping	similar models could be used in time charter rates of LNG shipping

23	The non-linear dynamics of spot freights in the tanker markets	Roar Adland, Kevin Cullinane	Transportation Research Part E	non-parametric Markov diffusion model used to investigate the dynamics freight rate in oil transportation markets	There is no study regarding LNG markets using similar model
24	The impact of crude oil price on the tanker market	Wenming Shi, Zhongzhi Yang, Kevin X. Li	Maritime Policy and Management, 2013	Structural Vector Autoregressive model has been used to study the relationship between fluctuations in crude oil prices and tanker ships markets.	SVAR model could be used for LNG shipping markets also

Figure 2.6 List of research articles related to volatility in shipping freight markets

Sources: various journal databases

2.4.3 Volatility in Ship Building prices

The early studies related to Newbuilding and Second hand ship prices were discussed by H.E. Haralambides in (Haralambides, Tsolakis, & Cridland, 2004) and (Tsolakis, Cridland, & Haralambides, 2003). Here ECM-AR model and SEM-AR models have been used for forecasting newbuilding and second hand ships respectively.

ARIMA and GARCH models have also been applied for forecasting newbuilding prices in tanker market (Geomelos, 2012). GARCH, EGARCH and ARIMA-GARCH models were applied to investigate newbuilding prices of ULCC, VLCC, Suezmax, Aframax, Panamax and Handy size vessel prices. GARCH process was found to be stationary for vessel categories and EGARCH models show presence of asymmetries in all categories of vessel newbuilding prices. However, ARIMA-GARCH model was found to have poorest predicting accuracy in compared to a simple GARCH and ARCH models. GARCH-M models have been used again by Kavusssanos (Kavussanos & Alizadeh, 2002) for understanding time varying risk in pricing of ships newly-built and second hand ships of Capesize, Panamax and Handysize category of dry bulk ships. Multivariate GARCH model has been used by Lei Dai (Dai, Hu, & Zhang, 2015) to understand the volatility spill over effects across new shipbuilding and second hand ship markets and freight markets. BEKK GARCH model has been utilised to capture the volatility transmission effect in the new shipbuilding markets, second hand ship markets and freight markets of dry bulk industry. We may conclude from the discussion that GARCH (1,1), EGARCH and asymmetric GARCH models were found to be more suitable in dry bulk and tanker markets. A consolidated list of research articles as discussed above have been listed below.

S. No.	Paper Title	Authors	Publication and year	Theme	Research Gap
1	Econometric Modelling of second-hand ship prices	SD Tsolakis, C. Cridland, H.E. Haralambides	Maritime Economics and Logistics,2003	ECM-AR models used for modelling second hand ship prices of dry bulk	similar models could be used for LNG shipbuilding prices forecasting and volatility
2	Econometric modelling of Newbuilding and Second hand ship prices	H.E. Haralambides, S.D. Tsolakis and C. Cridland	Research in Transportation Economics, 2005	SEM-AR models used for modelling new build and second ship prices of dry bulk and tanker ships	similar models could be used for LNG shipbuilding prices forecasting and volatility
3	A comparative study of ARIMA and GARCH models in forecasting	Nikolaos D. Geomelos	Conference proceedings, SNAME 2012	GARCH, EGARCH and ARIMA-GARCH models used for forecasting ship building prices of tanker market	similar models could be used for LNG shipbuilding prices forecasting and volatility

	newbuilding prices in tanker market				
4	Efficient pricing of ships in the dry bulk sector of the shipping industry	Manolis G. Kavusssanos, Amir H. Alizadeh	2002	GARCH-M models used to investigate volatility in dry bulk new ship building prices	GARCH-M models could be used for pricing of new build LNG ship prices
5	An Empirical analysis of freight rate and vessel price transmission in global dry bulk shipping market	Lei Dai, Hao Hu, Di Zhang	Journal Traffic and Transportation Engineering, 2015	Multivariate GARCH and BEKK- GARCH was proposed to study the price transmission in second hand and new build ship prices of dry bulk ships	GARCH and BEKK GARCH could be used in LNG new ship building prices to study transmission
6.	Price risk modelling of different Size vessels in the Tanker Industry using ARCH models	Manolis G. Kavusssanos	The Logistics and Transportation review,1996	Measurement of Volatility risk using ARCH models for world tanker ship prices	ARCH method not used to find volatility in LNG ship prices

7.	Price and volume dynamics in second hand dry bulk and tanker shipping	Theodore Syriopoulos, Efthimios Roumpis	Maritime Policy, 2007	GARCH, EGARCH models used to understand the relationship between prices, trading volume and volatility in tanker and second hand dry bulk market.	GARCH, EGARCH models could also be used to find volatility in LNG ship prices
8.	Price Volume relationship in the sale and purchase market for dry bulk vessels	Amir H. Alizadeh and Nikos K. Nomikos	Maritime Policy and Management, 2010	E-GARCH models used to find the relationship prices and trading activity in purchase and sale markets of second-hand dry bulk markets	E-GARCH models could also be used in LNG ship markets

Figure 2.7 List of research articles related to volatility in ship building prices

Sources: various journal databases

2.5 Research gap

From the above discussions and detailed literature review, the research gaps can be summarised below

1. The Literature review suggests that most of the studies were done related to comparative energy market prices like Crude oil, Electricity prices, JCC and Henry Hub. However, exclusive comparative studies between Henry HUB and Japanese Crude Cocktail prices were not done.
2. Volatility and GARCH models related to Bulk shipping freight markets have been studied but LNG shipping markets are yet to be investigated.
3. Volatility and GARCH models have been applied in new ship building prices and second hand ship building prices of dry bulk and tanker ships for analysis. These models are to be explored in New build shipping and second hand ship market prices.
4. GARCH (1,1) and EGARCH models were found to be very popular and appropriate models among GARCH family for understanding volatility and forecasting.